Photographic Optics.

A TEXT BOOK

FOR THE

Professional and Amateur.

— BY —

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PREFACE.

PHOTOGRAPHERS have long felt the need of a practical text-book on photographic optics. No subject is more important for them to thoroughly understand; yet, strangely enough, few subjects connected with photography have received so little attention by those who are qualified to teach.

It is with especial satisfaction, therefore, that this reliable instruction book, written by an authority, is sent forth on its career of usefulness by

THE PUBLISHERS.

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Photographic Optics.

CHAPTER I.

Light.

We all have a pretty fair notion of what we mean when we talk of "light," and yet when an attempt is made to give a precise definition of the term, to limit its meaning closely, the difficulty is by no means small.

The first idea of light, and one which is strictly correct so far as it goes, is "that which enables us to see objects;" and the question what is this which gives us the power will probably elicit from a scientist that it is a form of "radiant energy," which statement is also probably strictly correct, but requires a little investigation.

Taking the word "energy" first. This word is commonly defined as "the power to do work," or, in other words, to "produce motion against resistance."* Energy may show itself in many forms, as, for example, heat, light, and electricity; or again, the energy may be in the form called "potential" being, that is to say, stored up, not showing itself in any way, but prepared to do so when certain conditions are fulfilled. Again, the energy may be kinetic. The energy possessed by, for example, the weight of a clock which has just been wound up is potential; the energy of that weight were the supporting chain to break would be the kinetic, to a

* R. J. Glazenbrook, "Physical Optics."

certain extent, at any rate. In each case it is energy, inasmuch as it is capable of producing motion against resistance. In the first case the motion of the works of the clock against the resistance of friction, and in the second place the motion of anything which happens to be in the way of the falling weight—against the resistance of inertia if nothing else. In both cases the energy will, for the most part, eventually change its form from that of potential or kinetic energy into that of heat—another form of energy. For it is one of the fundamental principles concerning energy, that although it can be changed from one *form* to another, its destruction *as energy* is, so far as we know, impossible. This great principle is known as "the conservation of energy," and along with another, the indestructibility of matter, forms the basis of nearly all modern scientific reasoning. Neither principle can by any means be taken as absolutely and eternally true; all that we can say is that, within the limits of the sphere of human reasoning, they are to all intents and purposes true, and form a most useful basis for working on.

The law of the conservation of energy is thus stated by Prof. Maxwell: "The total energy of a body or system of bodies is a quantity which neither be increased nor diminished by any mutual action of their bodies, though it may be transformed into any of the forms of which energy is susceptible."

To take a practical and familiar example, we place in the fire-box of the boiler attached to the engine of a steam crane a certain quantity of coal. This coal contains a vast amount of energy in the potential or latent form, not making itself apparent to any of our senses, but requiring only that certain conditions will be fulfilled when the potential energy will be changed with various other forms. The conditions are the presence of oxygen with which the carbon and hydrogen of the coal may combine, and, generally, some internal stimulus to start the combination. In plain language, the fire of coals wants air and requires to be lighted.

We now immediately have energy exhibited in two forms —light and heat. A certain amount of light will probably escape by the furnace door, and possibly by the chimney.

That which is confined to the fire-box will be converted into heat by a process which it is impossible to follow. The greater part of it, however, is converted directly into heat, and the most of this heat is absorbed by the water in the boiler. Some of it, however, escapes up the chimney.

We shall suppose the engine used to lift a heavy weight, let us say a weight of one ton, to a height of fifty feet. When the engine is started, the greater part of the energy goes off in the form of the heat of exhaust steam. It can, however, be proved that a certain amount of the heat has taken the form of electricity, and that some of the energy is being used to perform work—that is to say, lift the ton weight to the height mentioned, fifty feet. When this weight has been lifted and put in position so that it is supported at a height of fifty feet above its first position, a certain definite amount of the energy that was at first latent in the coal is now in the "potential" form in the weight. The rest of the energy has been dissipated in the various ways indicated—by far the greater part of it in the form of heat—but could it all be collected together again it would be found to be precisely the same in quantity as before the coal was lighted; or, to go farther back, because it is supposed that the coal got its energy by absorbing some of that radiated from the sun when it (the coal) was a living tree, the same in quantity as when it was sent from the sun thousands of years ago, and was absorbed by a plant growing on the surface of the earth. Nay, we might go farther back, and accepting the nebular theory, trace the energy to that time when it was potential, or energy of *position* due to the enormous distance of the greater part of the nebulous mass from its center of gravity.

But, to follow the portion of the energy that is stored up in the weight lifted, this can readily be converted into other forms of energy. If the support of the weight be removed and the weight be allowed to fall, the energy will be converted from the potential into the kinetic form. Leaving out of the question air frictions, by the time the weight has fallen fifty feet, the whole of the energy which was passed from the coal to it, and which was in the potential form, has become kinetic.

At any time before it has fallen the fifty feet a portion is kinetic, a portion potential. Thus at twenty-five feet one-half of the energy is kinetic, the other half is potential, and as the body continues to fall the rest of the potential energy is transformed into kinetic energy.

As we have left air friction out of the question, we must suppose the falling of the body to take place *in vacuo*. We shall suppose that when it has fallen fifty feet it comes to rest, striking some hard substance. The energy is still not lost, but is merely converted into heat, probably a little light, and possibly some electricity. The falling body and whatever it fell on have both been heated, and had the experiment been performed in darkness a flash of light would pretty certainly have been seen to accompany the coming to rest of the falling object. It is further likely that there has been some greater or less electrical disturbance, and that a little of the energy has gone in this last-mentioned form. The whole of it, however, could it be collected together, would be just sufficient to raise the weight to the place from which it fell.

We have here seen energy changing its form many times and being divided up into different forms of energy, and this, although we have not taken into consideration at all various of its phases, as when steam was stored under pressure in the boiler, when the same steam was expanding in the cylinder, etc. Still, all these forms of energy could, with greater or less ease, be placed in one or other of two classes—potential energy and kinetic energy—the one typified by the weight ready to fall or by a coiled-up spring, the other typified by the falling weight or by a projectile that might be discharged by the uncoiling of the spring. Thus, heat, as exhibited in the fire, in the water and steam of the boiler, in the exhaust steam from the engine, in the weight that has fallen, and in the body that it has fallen on, are all supposed to be phenomena of the extremely rapid movement of the atoms or molecules of the various substances. The same may be said of the light, and probably of the electricity. Indeed, it is possible that at some time all forms of energy may be explained in terms of motion alone.

We are to consider light, then, as one mode in which the energy of a body becomes known to us; and luminous bodies are those which are of themselves capable of changing part of the energy they possess or receive into this form.

The same definition may be given of heat as of light, and there are few cases when light is given off where heat is not given off too; and, in fact, there is no hard and fast line to be drawn between heat and light. Both are supposed to be phenomena of a very rapid vibration of particles, the light, on the whole, of a slightly rapider vibration than the heat; but, especially in considering photographic action, it would be well were no distinction attempted between the two, but were some such name as radient energy used to designate those forms of light and heat which may be capable of photographic action. It will be understood that when we speak of light we use the term in this meaning.

Light, then, we suppose, has its origin in the conversion of some of the energy of a body into an extremely rapid motion of the atoms of that body; but something more is necessary to account for the transmission of the light from its source to a distance. The theory of Newton, known as the "emission theory," was that the light-giving body threw off material particles which traveled in all directions in straight lines. Insurmountable difficulties were found to stand in the way of the general adoption of this theory, and the "undulatory theory" took its place. By this it is assumed that the whole of space is filled with a substance to which the name of ether has been given, this ether being imponderable, and being made sensible to us only when thrown into a state of inconceivably rapid vibrations. It is assumed that sources of light communicate the vibration of these atoms to the ether, which takes up that vibration and transmits it to a distance.

Newton's difficulty in accepting this hypothesis lay in the fact that he could not explain, on the vibration theory, the rectilinear transmission of light—the fact that an opaque body (one which did not permit the passage of the vibration) should cast a shadow; that the vibration should not pass round

the opaque body, as sound passes round a solid body which will not transmit it.

The rectilinear transmission of a vibration has, since Newton's time, been explained, and most, or all the phenomena of light which have been investigated have been found to be compatible with the undulatory theory. The explanation of the fact that light travels in straight lines only (with exceptions that will be hereafter considered) is too complicated to insert here. Those who wish to investigate the question further are referred to the book already mentioned in a foot-note.

The vibration which transmits sound through the air, or any other elastic medium, is supposed to consist of a motion of the atoms of the elastic body in the line of the direction of the traveling sound; that so long as the sound continues each particle of the medium through which it is passing keeps oscillating in the direction of and away from the source of sound. It is quite different, however, in the case of light. In this case it is necessary, to render the vibration theory compatible with various phenomena, to suppose a vibration of the ether transversly to the direction in which the light is traveling. It should be here pointed out that we cannot talk of particles, atoms, or molecules of the ether moving transversely to the direction of the vibration, as the ether is supposed to be a homogeneous substance, one of infinite divisibility, and of complete indivisibility which comes to the same thing. In fact, one of the theories of atoms is that they consist of centers of motion of the ether, these centers of motion being in the form of vortex rings.

To render a transverse vibration conceivable, the following experiment is commonly performed. A flexible cord is allowed to hang freely from a high roof. Glazebrook recommends particularly an elastic (India-rubber) tube filled with sand as the most suitable. The lower end of the tube is held in the hand, and a sharp transverse motion is given to it; that is to say, the tube is quickly moved in a direction at right angles to its length. A single vibration will now be seen to travel quickly up the tube, to, so to speak, strike the place where the tube is fixed, and to return to the hand, which will feel a

distinct jerk. Now this vibration undoubtedly traveled in the direction of the cord, yet each part of the cord moved at right angles to its direction, or transversely to the direction of the vibration. This vibration is somewhat of the nature of that imagined for light, and, indeed, the return of the vibration down the tube may be taken as roughly typifying the reflection of a beam of light.

In the case imagined it has been supposed that the hand was jerked in a straight line (approximately) in a direction at right angles to the length of the cord, but this jerk might consist in making the lower end of the cord rapidly describe a circle. The vibration would, in this case, travel along the cord just as in the other, and if the end of the cord were kept continually turning, so as to rapidly describe the same circle over and over again, there would be a continuous transference of vibrations along the cord. This is, perhaps, the nearest physical representation that we can get of the supposed manner of the transmission of light by transverse vibrations through ether.

The speed of light, and the smallness of the vibrations, are such as not to be really conceivable to the mind. Approximately, light travels 185,000 miles in a second of time, and in each inch of all these miles there are, for an average beam of light, about 44,000 vibrations. I say for an average beam of light, for all light that we know of is compounded of vibrations of different lengths. It will be understood that the length of a vibration is the distance between any point of one wave of the vibration to a similar point in the wave immediately before or in front of it.

I have already said that, in considering the radient energy which acts photographically, we can make no hard-and-fast line between what is commonly called heat and what is commonly called light, in that it is visible to the eye; but as a general and approximately correct truth, it may be said that the greater part of heat phenomena are produced by waves longer than those mentioned (having fewer to the inch); the greater part of sight phenomena—in the case of human beings, and at any rate probably in the case of all the larger higher

animals—by vibrations of about the length mentioned; the greater part of chemical phenomena, such as are made subservient to photography, to vibrations shorter than those mentioned, that is to say, of which there are a larger number to the inch.

I have, in the foregoing brief exposition of the undulatory theory, carefully treated it as a hypothesis only, and it must always be borne in mind that it is nothing more. No human being has ever thoroughly even conceived of the vibration of ether, which is said to transmit light. It is, however, commonly said that the undulatory theory, if too subtle to be quite conceived by the mind, *explains* most of the phenomena of light. This it certainly does not do. It is really only a nearly conceivable hypothesis which is *compatible* with most of the phenomena of light which have been investigated, and without assuming which it appears, in our present state of knowledge, impossible to account for some of the phenomena. As such, it is very useful, because it may be assumed by analogy that it will be compatible with many others, and these may be first worked out on that assumption. Every problem worked out by this and of the hypothesis, and found to give results agreeing with facts, strengthens the said hypothesis, and renders it more likely that it is a true one.

Having thus explained that the undulatory theory is to be taken as a hypothesis only, I shall, to save continual repetition of this explanation whenever the words or expressions "undulation," "wave of light," and so forth have to be touched on, talk as if the theory were an established fact. Of course this includes the admission of the existence of ether, although it by no means involves even the assumption that the atoms which compose matter are formed out of this ether, in the sense of consisting of centers of motion of its substance (if one may apply the term *substance* to such a thing as ether) or in any other sense.

CHAPTER II.

On the Reflection, Transmission, and Absorption of Light by Matter.

So far we have considered merely the body from which light emanates, the "source of light," and the transmission of the light from this source through space. We come now to a brief consideration of the effects produced when this light comes in contact with any material object—with matter, to put it briefly.

It is necessary, before going further into this, to consider very briefly the atomic theory of matter. To go fully into a consideration of this question here would be quite out of place; those who wish to do so may consult the article "Atom," in the latest edition of the "Encyclopædia Britannica."

Briefly put, it is assumed in the atomic theory that all matter is made up of innumerable small fragments called atoms, and that the distinctive feature of these atoms is that they are indivisible and indestructible; also that they are capable of individual motion. It is assumed, further, that these atoms are in motion in the case of all matter that we know of; that there are atoms differing one from another in some such way—either by being individually different, or by forming themselves into different groups—as to make them constitute, when in motion, different kinds of matter. Further, it is supposed that these atoms, whether several of one kind, or several of various kinds, are capable of building themselves up into systems, which are called molecules. By a stretch of imagination we may illustrate a piece of matter by the whole of the universe that we know of, supposing each celestial body to be an atom. The conditions are so far fulfilled that these bodies are in continual motion. A molecule may then be conceived as illustrated by a solar system, or

by one of the systems of fixed stars that we know of, in which there are very special motions of each of the bodies of the system in relation to the others.

The different states of matter—as solid, fluid, and gaseous—are, in the molecular theory, supposed to be attributable to different degrees of motion of the atoms.

Much discussion as to what constitutes an atom, what are its physical properties when isolated, has taken place. Some have supposed atoms to consist of minute elastic spheres, thereby assuming, in an atom, one of the very properties—elasticity—for the explanation of which the actomic theory was invented. Others have supposed them to be centers of force, of attraction and repulsion merely. There are many other theories, amongst which that of Sir William Thomson, already mentioned, stands pre-eminent. He has supposed that atoms consist of vortex rings, which may be physically represented by the rings of smoke which some smokers can blow from their mouths, these vòrtex rings being, however, formed in an atomless ether in place of in the air. At first sight this idea seems so preposterous that it might be dismissed without further consideration; yet a careful investigation of it shows that it carries with it fewer objections than any other theory for the formation of atoms that has ever been enumerated. The properties of "vortices" investigated by Helmholtz and Thomson are so very remarkable that scarcely anything is too extravagant to expect from them; further, the theory is better than any other, inasmuch as it requires much more molecule assumption than any others; in fact, it requires the assumption merely of an ether, consisting of a primitive fluid having no other properties than inertia, invariable density, and perfect mobility.*

So much having been said of the atomic theory, it is necessary to state, as in the case of the undulatory theory, that it is merely a theory, inasmuch as, without requiring assumptions which it is impossible to grant, it is compatible with many or all the phenomena which have been investigated with refer-

* "Encyclopædia Britannica," article "Atom."

ence to it; and that, without admitting it, it is impossible, in the present state of our knowledge, to account for some phenomena. In future, it is spoken of as if it were more than a theory—an established fact. This is done to avoid the necessity for continually repeating the statement that it is but a theory.

This much of the supposed nature of matter is preparatory to a few words as to the effects which are produced when an undulation of light in ether impinges or strikes upon matter of any kind. So far as we know, whenever light strikes any material object, one of three things takes place: either the light is reflected, it is transmitted, or it is absorbed. It would, perhaps, be more correct to say that in every case all three of these things take place, but in many cases one occurs to so much greater an extent than the other, that it may without much deviation from the truth be spoken of as if the others did not occur at all.

The general idea conveyed in the word reflection need scarcely be explained. It is simply a casting back of something which comes in contact with a material surface. In the emission theory, reflection was easily disposed of, on the assumption that the material particles which constituted the light rebounded from the surface as an elastic ball does when it strikes a wall. Accepting the undulatory theory, it is possible to imagine that the undulations of light transmit this vibration to the surface of the reflecting object, the atoms of which are capable of a vibration of the same period as that of the light striking them. They will then themselves be, so to speak, a source of light giving off new vibrations to the ether of the same kind as those they receive. There is no case of a perfectly reflecting body; every body which reflects light also either transmits or absorbs some of it, or does both things. There are many substances which reflect light of some particular wave-lengths between certain limits only. All colored substances are of this nature. It may be imagined that in the case of these the atoms are capable of answering to vibrations of certain periods, but not to those of others.

Reflection is a subject not of great importance in connection

with photography, except in so much that it is only in virtue of reflection that we are able to photograph objects at all, which can, it is true, scarcely be considered a trifling matter.

The well-known law of reflection must be stated. It is that when a ray of light strikes a reflecting body, the incident and reflected rays are in the same plane as each other, and as the normal, are on opposite sides of the normal, and form equal angles with it. The normal is a line at right angles to the reflecting surface at the point of incidence.

Substances which transmit light or allow it to pass through them are said to be transparent. There are no bodies which are perfectly transparent. All so called transparent substances reflect a certain amount of the light which impinges on them—as a rule, a greater quantity the more oblique to the surface the direction of this light—and absorb another certain amount.

Whether when light passes through a transparent body the atoms of the body simply permit of the passage of the undulations of ether between them without interference, or whether the atoms themselves vibrate and transmit the vibrations, has been a matter of dispute; but the fact that the velocity of light is changed, being reduced when it passes from vacuum to a transparent medium, would indicate that the atoms take part, at least to a certain extent, in the undulation or vibration, and indeed it is impossible—to the writer at least—to conceive that matter, constituted in accordance with Thomson's theory, should allow a vibration to pass through it without causing some motion of the atmosphere due to that vibration.

This change of velocity is a most important matter in connection with the action of light, as to it is due the fact that light is changed in direction, or is *refracted*, when it passes from vacuum into a transparent medium; or, as a rule, when it passes from one transparent medium to another—as, for example, from air into glass. This refraction is the cause of all the phenomena observed in connection with prisms, the spectroscope, lenses, and in fact the majority of so-called optical instruments. As, however, *refraction* needs to be

treated of at some length, I say no more of it here than that it is accounted for on the undulatory theory by the differences of velocity of light in vacuum and in various transparent media. It is scarcely possible here to enter into the explanation of the action whereby the retardation or acceleration of the velocity of a wave of light, falling obliquely on the boundary of two media, causes a change in the direction of the wave; but it may be said that the agreement of the fact here stated with theoretical action on the undulatory theory is considered as one of the great arguments in favor of that theory, as against the emission theory.

When light impinges on a body which neither reflects or refracts it, as when it strikes a black opaque body, it is said to be *absorbed*. This means that the energy of the light passes into the body in some form. It is not—except in a very few cases—strictly correct to say that the light, or any but a little of it, is actually absorbed. In most cases a certain amount of the light is absorbed, the energy going to cause vibration of the atoms of the body; these vibrations being, however, of such period that they do not make the body visibly luminous, but merely heat it. Such of the vibrations as were of such speed before as to give light sensations, serve to produce in the body slower vibrations, and it is commonly said that the form of energy is changed from that of light to that of heat. We have, however, already explained that in photographically considering light we cannot draw any hard-and-fast line between those undulations which are chiefly sensible through the sense of sight, and those which are chiefly sensible through their heating power. But to use the convenient popular phrase, which will be readily understood if taken with the qualifications just mentioned, after so much light has been converted into heat and to raise the body acted upon by the light to a certain temperature, energy is given off in heat as rapidly as it is absorbed in the form of light. It is given off in the form of radiation, by transmitting to the surrounding ether wave motions of a slower rate of vibration than that which was received from it; and, if the body be not isolated in vacuum, by communicating directly to the air around it, or

to other objects which are in contact with it, energy in the the form of heat.

There are a few cases in which light which is absorbed is given off in the same form in which it is received; that is to say, in which the vibrations are not reduced in period. The best examples of such bodies is the luminous paint now so well known. This possesses the power just mentioned in a very high degree, but there are very many bodies which possess it to a trifling extent.

There is yet another variety of absorption of light which must be specially considered, as it is of great importance in connection with photographic matters. In fact, to it may be said to be entirely due the possibility of photography. This is the form of absorption in which the energy of the light is exerted in changing in some way the chemical (or molecular) constitution of the body.

We take a piece of sensitive photographic paper of any kind—let us say that known as albumenized paper—and place it in the sunshine. It very quickly darkens. This darkening is the outward sign of some chemical change in one or more of the substances in the paper, or on its surface, and is due, strictly speaking, to a change in form of some of the energy which reached the paper as light.

We can by no means say for certain *what* is the change that takes place, or in what way it is brought about, but the following is a hypothesis. We shall suppose, for the sake of simplicity, that there is only one sensitive substance under consideration, and that it is a compound substance. Of such a compound substance each molecule is in the form of a system of atoms of at least two different kinds. We shall suppose, for the sake of simplicity, that there are two large atoms of one kind, and one small one of another kind. These are in continual motion relatively to one another; each one is supposed to be vibrating in a course in some way determined by the other two, and with a certain period of vibration. A vibration of the ether with which the atoms are surrounded, or of which they may be constituted, may communicate itself to these atoms. The hypothesis is that the vibration will

communicate itself more rapidly to an atom if the normal period of vibration of the atom is the same as the period of a vibration of the ether.

The physical analogue of this is to be seen in the case of a pendulum, which may readily be made to swing through a considerable arc if given a series of very slight impulses at periods corresponding with the natural poriod of the swing of the pendulum, but cannot be caused to swing through nearly so large an arc by much stronger impulses applied at other periods; as in the case of the famous experiment at the Menai Bridge, when it was found that the whole structure could, by the concerted action of a few men pushing it at periods corresponding with its natural vibration, be deflected through a much greater distance than by a storm of wind which applied hundreds of times the force that the men applied.

We may now suppose the smaller of the three atoms that we have imagined to have a period of oscillation equal to that of the undulation of light which is brought to play on it. It is supposed that the oscillation of the atom is increased to such an extent that it disassociates itself from the other two, and flies off either by itself in what is technically called the "free" form, or to join itself with some other atom to form a new molecule; in other words, to form a new combination or chemical substance.

This is—perhaps not very well described—the molecular theory of the chemical action of light, supported, and I believe first enunciated, by Abney. Granted the atomic and the undulatory theory, it appears to be sound enough, but of course it can only be taken as a theory. We do, however, know that light may use its energy to change the chemical composition of certain bodies. To this action is given the name of photographic action.

CHAPTER III.

Refraction of Light.

We have mentioned that a ray of light in passing from a vacuum into any transparent substance usually has its direction changed, and that the same occurs when it passes from one transparent medium to another. There is also a change of direction when the ray leaves the transparent body.

The law of refracton is commonly stated as follows: "The incident and refracted rays lie in a plane which also contains the normal at the point of incidence, and on opposite sides of the normal. The refracted and incident rays make with the normal at the point of incidence angles, the ratio of whose lines depends only on the two media, and the nature of the light."

The ratio existing between the size of the angle between the incident ray and the normal in vacuum, and the size of that between the refracted ray and the normal, is called the refractive index for that particular medium.

This for completeness sake. We now go on to consider the bearing of these facts on certain forms of transparent objects, leaving all technical scientific phraseology on one side.

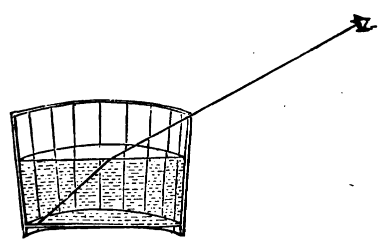


Fig. 1.

The most popular illustration of refraction is that in which a coin is placed in the bottom of an empty tub at such a position that an observer stationed at a certain point is just unable

to see it. The tub is then filled with water, when the bending of the ray of light enables the observer to see the coin. We illustrate this case of refraction here, although it is not the happiest illustration of refraction that could be chosen as a first example, because the bending of the ray of light takes place in the passage from a dense medium (water) into a comparatively rare one (air), where, as in most cases of refraction that we have to deal with in optics, the ray passes first from a rare into a dense medium.

We shall take the case of a ray of light striking obliquely the surface of a thick sheet of glass or of some similar transparent substance. But just let us say that in all cases of refraction to be here considered, the *air* may be left out of consideration, and it may be taken that the results are the same as if the ray of light entered the transparent medium directly from vacuum.

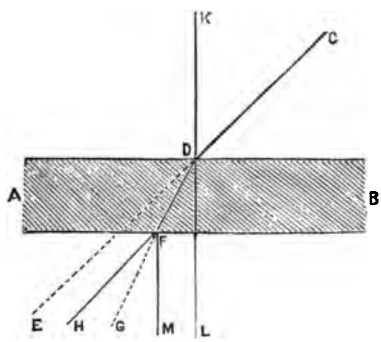


FIG. 2.

In the accompanying sketch we imagine A B to be a thick sheet of glass with parallel sides. C D is a ray of light incident to the upper surface striking it obliquely.

The ray of light will not continue directly on its course towards E; but will have its direction changed, so that it strikes the lower side of the sheet of glass at F. Here, however, it again does not continue in a straight line, which would carry it to G, but is once more bent, taking the direction F H, which is parallel with that D E or C D. In this case, there-

fore, the ray issues in a direction parallel with its first directions, but not in line with it.

The line K D is a line at right angles to the surface of the glass where the ray of light is impinged on it. D L is a continuation or production of that line. The whole line K L forms the "Normal." It is to be observed that on entering the glass the light is bent *towards* this line. F M is at right angles to the lower surface of the plate of glass at the point where the ray emerges, and it is to be observed that the ray is bent *away from* this line. This is a very important point to remember, and I repeat it in general terms. A ray of light obliquely entering a transparent substance is bent *towards* a line drawn at right angles to the surface of the point of entrance; a ray of light leaving a transparent substance is bent *away from* a line drawn at right angles to the surface of the substance at the point of exit.

The importance of this matter will very soon be perceived. In the case that has just been taken, and which has been illus-

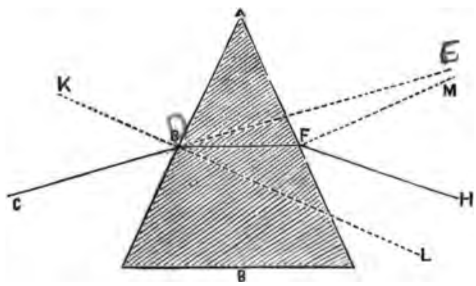


FIG. 3.

trated by a sketch, the two surfaces of the transparent body were parallel, and the ray of light issued parallel with the direction in which it entered; but had the surface of the body not been parallel the issuing ray would have had its direction changed; in other words, it would have been completely bent in passing through the transparent body. On this fact depends the whole of the structure of lenses, and of the greater number of optical instruments.

To take a special case, namely, that of a prism. A prism is here illustrated, or to speak more correctly the section of one.

We have now, supposing C D to be a ray of light falling obliquely on one side of the prism, only to bear in mind that it will bend *towards* the line K D L at right angles to the entering surface, and *away from* the line F M at right angles to the surface of exit, to see that it will take a direction something like C D F H, and to see further that the direction of the outgoing ray of light, F H, is quite different from that of the continuation or production of the line C D, shown as the dotted line D E. It will easily be understood that, by making use of this property of certain forms of transparent bodies of bending rays of light, we have a great power. We shall go on to show how this power may be made use of in the construction of what is known as a lens.

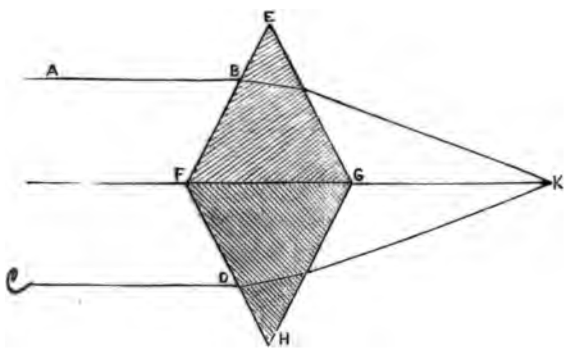


FIG. 4.

X We have only to imagine two prisms F E G, H F G placed base to base, and to imagine two rays of light A B and C D to impinge on these prisms; when, if we follow the

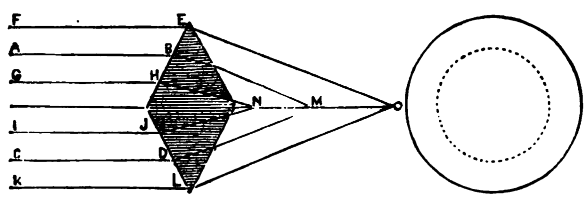


FIG. 5.

course that these rays must take, we shall find that they meet at K. We may further suppose the prism bent into a circle, so as to be in section and plan as shown in the sketch

(Fig. 5); we should then find that all rays falling on a circle of the disk, concentric with the circumference—as shown by the dotted line—will be brought to meet together at one point, but that those reaching the disk in circles nearer the center will meet together at points nearer the disk; those reaching in it circles farther from the center, farther from the disk. This is shown by the rays G H, I J meeting at N, those E F, K L meeting at O.

We have, however, only to give the surface of our disk of glass certain curvatures, when we may have all the rays meeting at a point, as shown in the next cut. We have now got a

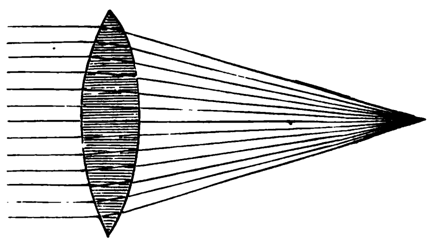


FIG. 6.

lens of the simplest form, a piece of glass which has the property of bringing all parallel rays which fall on it to a point.

I have talked here of the surfaces as curved without specifying any particular curve, and I may say that the curves necessary to cause rays to meet at a mathematical point are such as can scarcely be employed in practice; that practically

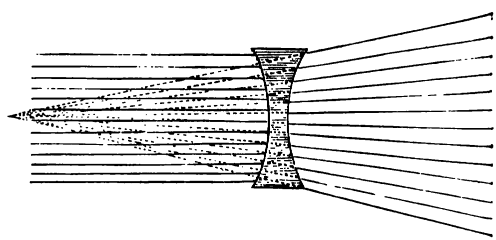


FIG. 7.

the curves are generally spherical, and that, with spherical curves, the rays are only brought approximately to a point. This subject will be specially treated further on, under the heading of "spherical aberration."

All lenses do not cause rays of light to meet together. There is, on the contrary, a class of lens that causes them to separate. This form of lens is illustrated in Fig. 7—or rather one of the many forms which a dispersing lens may take is illustrated.

The point at which, in the case of the first form of lens, the rays of light meet is called the focus. The dispersing lens is said to be of negative focus, the negative focus point being that where the outgoing rays produced (as shown by the dotted lines in the cut) meet.

All lenses may be classified under one or other of the headings "condensing" or "dispersing." There are various forms, the most commonly used of which are shown here.

Fig. 8 shows a set of converging lenses, Fig. 9 a set of dispersing. These different forms of lenses are designated by

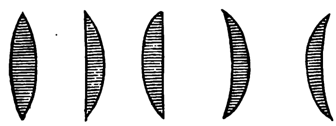


FIG. 8.

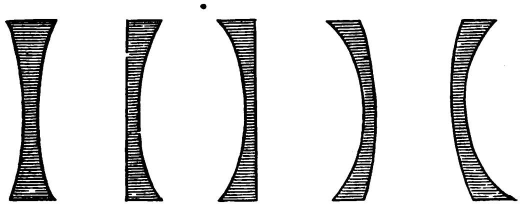


FIG. 9.

various names, as double convex, plano-convex, convexo-plano, and so forth. When compound words are used the first of the two designates the surface that the light first reaches.

When the surfaces are both curved, and the centers of curvature of both surfaces are on the same side of the lens—as is the case with both the last two lenses in both Fig. 8 and Fig. 9, the lens is called a meniscus.

We must now go back to a consideration of the simple prism, and of the fact of which, for the sake of simplicity, we

made no remark before, namely, that a ray of white light is composed of rays of light of all the colors of the rainbow, that on passing through the prism these rays are all bent, but are not bent to the same degree, some suffering a greater deviation from the original direction than others. This may certainly be said to be a fortunate fact, inasmuch as the whole science of spectroscopy depends on it; an unfortunate fact, inasmuch as it complicates the structure of almost every optical instrument except the spectroscope.

The annexed cut shows the way in which light is split up into the colors violet, blue, green, yellow, orange, and red. The first mentioned of these is bent the most, the last the

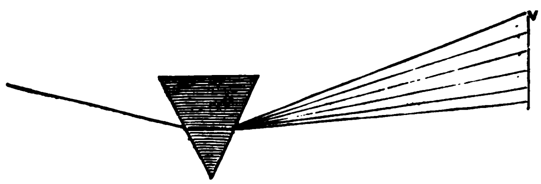


FIG. 10.

least, and it is common to speak of the rays causing the colors at the violet end of the row as the "more refrangible," those at the other as the "less refrangible." If a lens be now considered it will at once be perceived that there must be a similar splitting up of light by it, and that in place of parallel rays being brought to meet at a point, they will be brought to meet at a series of points, the violet light nearer the lens than

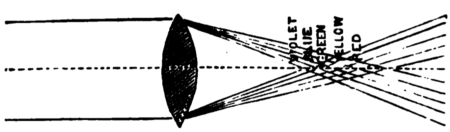


FIG. 11.

the other colors, the red being the farthest away. Fig. 11 will serve to explain what is meant.

Newton, with a rashness which was not in keeping with his usual caution, declared the defect to be irremediable, but a remedy at least nearly complete was found for it when it was

discovered that although all transparent bodies disperse light as well as refract it, all do not disperse and refract in the same proportion. Thus some kinds of glass which refract or bend an average ray of light to a considerable degree, disperse it to but a small degree, and *vice versa*. It is, therefore, possible by using a glass of great dispersing power, but little refracting power, in combination with one of great refracting and little dispersing power, to bend a ray of light without splitting it up into its component colors, or more strictly speaking, to recompose the decomposed light without altogether altering its direction.

The next cut shows (in an exaggerated fashion) the action of two prisms, one with great refracting and small dispersing

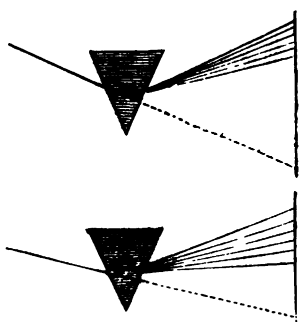


FIG. 12.

power, the other with great dispersing and small refracting power.

The next figure will, it is hoped, make clear how two such

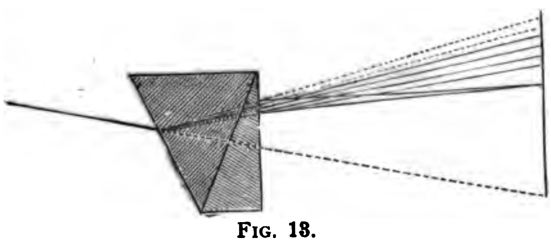


FIG. 13.

prisms, being united, may result in what is called achromatism. The word means, ethnologically, simply "no color." In optics

it always applies to the bending of a ray of light without decomposing it into various colors.

Flint glass has, proportionately, much more dispersing power, as compared with refracting power, than has crown glass. The correction of the dispersion given by a crown glass prism can therefore be effected by that of a flint glass without strengthening the ray of light. We have only to apply the same principle in the case of lenses, placing a dispersing flint lens behind a condensing crown glass lens,

FIG. 14.

when we correct the defects due to the breaking up of white light into various colors. I show here several methods of applying the principle.

In each case the concave or dispersing lens is of flint glass, and is used solely to counteract the dispersion of the other lens. It will be seen that in the case of the third illustration there are in fact three lenses. The principle, however, is the same as where there are but two. It may be considered that the crown lens is split in two, certain advantages arising from this arrangement.

It should be said here that there is no such thing as absolutely perfect achromatization, there being always what is termed a small "residual spectrum." It may, however, be taken that, so far as photography is concerned, it is easy to obtain such approximation to achromatism as is necessary.

CHAPTER IV.

THE FORMATION OF THE IMAGE IN THE PHOTOGRAPHIC CAMERA —PHOTOGRAPHIC LENSES.

WE now come to consider the way in which the image is actually formed by the lens in the photographic camera.

It is a very old experiment to make a small hole in the shutter of a darkened room, and to place opposite to this hole, and at some distance from it, a sheet or any other white screen, when an image—somewhat blurred, but still recognizable—of whatever scene may be outside the window is obtained. The image is formed by light passing from all points of the object through the hole in the shutter and falling on the screen. The blurring is due to the fact that the light coming from a point reaches the screen as a disk at least as large as the hole. We may stop down or decrease the size of the hole, but the result is, that whilst we increase the definition or sharpness of

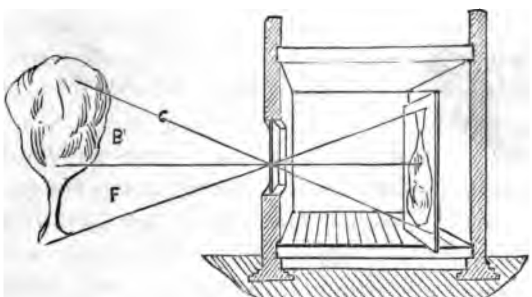


FIG. 15.

the image, we lose brightness, because we cut down the amount of light. It is here that the lens comes in. The function of a converging lens is, as has been explained, to cause parallel rays to come together at a point. It will perform the same function for slightly divergent rays. We have then merely to

place in the hole in the shutter a lens of such form that it will cause the rays which fall on it from the scene outside to converge to points on the plane of the screen, when we get a sharp image, even if we greatly increase the size of our opening.

The action of the lens is here indicated by a sketch.

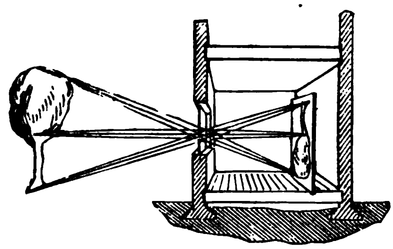


FIG. 16.

I have here, for the sake of simplicity, shown a double-convex lens without correction for chromatic aberration or for any other defects, and, as a matter of fact, even such a lens will give, with a considerable aperture, a better image as regards definition than will be got with quite a small aperture without a lens. It will, however, give nothing like the definition needed in photography, and is defective in many ways. The whole science of photographic lens-making consists in doing the most possible to overcome the defects inherent in a lens such as that shown. I say the "most possible," because to overcome them entirely is not possible, for the reason that a complete correction of one defect would generally lead to the increase of others. As a consequence, the whole thing has to be a compromise. The errors are compromised in various ways; hence, various forms of lenses. The different forms are for the most part adaptable to different uses, because, in certain cases, some particular fault is less tolerable than in others, and may be allowed to exist in order to get rid of other faults which might be, in that particular case, entirely damning. To take an example. The requirements in a lens to take a portrait are quite different from those in one for landscapes. In the former case, if the instrument gives the head

and the principal parts of the figure sharp, the rest may be more or less in poor definition, or blurred; but we require great rapidity of action. In the case of the latter, we need sharp definition everywhere, but rapidity is not of consequence. Again, in the case of architectural work, no distortion is allowable, or straight lines will be shown as curved lines. In pure landscape work, where there are no straight lines, a little distortion is quite imperceptible, and a simple form of lens having certain advantages of its own may be used.

As photographic lenses are, in practice, constructed to compound for certain defects, so as to make each form of lens adaptable to certain uses, it is necessary, before going farther, to say a few words on such defects, and to explain terms commonly used in speaking of lenses.

A lens is, strictly speaking, a single piece of a transparent substance fashioned into one of certain forms, as described in the last chapter; but in photography the term is used both in this sense and as describing an arrangement of several such lenses—often four or even more—as will be presently illustrated. Indeed, the way in which this term and some others are used is very puzzling, and often leads to confusion. Thus we have the word used in the two senses just given. Then again a "single lens" generally means two, sometimes three lenses cemented together. The same arrangement is often described as a "combination," so that a "single lens" and a "combination" may mean the same thing. The word "combination" also describes any arrangement of lenses very close together in one cell—whether they are cemented one to the other or not. A more correct term is "element."

The focal length of a lens is, roughly speaking, the distance between the lens and the plane where a sharp image is obtained. More correctly speaking, it is the distance between the point through which pass lines joining points in a distant object, and corresponding points of the image of that object, and the plane where parallel rays are brought to a focus. Farther on, various ways will be described of practically measuring the foci of lenses.

The terms "equivalent focus" and "back focus" are very

frequently heard. Equivalent focus really simply means focal length. It is applied to compound lenses in which a direct measurement from one of the elements cannot be made. The idea conveyed is that this is the focal length of an "equivalent" lens—one giving the same size of image, etc.—of the form of a small double convex glass. In such a lens the measurement may be from the center of the glass.

The term "back focus" means only the distance between the back combination or element and the ground glass when a distant object is focused. It is scarcely ever of any moment to know it, and, indeed, it would almost seem as if the term had been invented by opticians for the sole purpose of hopelessly confusing the uninitiated, already suffering from quite sufficient confusion in the matter of lenses.

The optical center of a lens is the point through which pass the axes of pencils of light. It is common to measure the focal length from this point, but the practice is not strictly correct.

The aperture of a lens is the diameter of the glasses, or of the smallest opening that light has to pass through in the lens. It is commonly stated in terms of the focal length thus—$\frac{f}{4}$, $\frac{f}{9}$, $\frac{f}{11}$, these terms meaning apertures one-fourth, one-ninth, and one-eleventh of the focal length, whatever they may be.

Diaphragms or Stops.—In many, or in fact most, lenses the light has to pass through an opening smaller in diameter than the lenses. This opening is termed the fixed stop. Most lenses have, and every lens should have, a series of movable disks with round openings of various diameters in them for reducing the diameter of the aperture when it is found desirable so to do. These are called diaphragms or stops, although the first of the two terms is not a very correct one.

Spherical Aberration.—If it were possible to make a lens in which parallel rays of light were caused to meet at a mathematical point, such a lens would be devoid of spherical aberration. As a matter of fact, certain compound lenses—especially telescope objectives of a high class—come very near to perfection in this respect; but, in the case of a simple lens with spherical surfaces, the rays by no means all meet at one point

—those which impinge on the margin of the lens coming to a focus, or meeting, nearer the lens than those passing through points near the center. Fig. 17 illustrates the condition we have described.

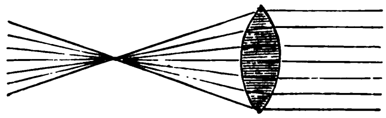


FIG. 17.

The practical result of the existence of spherical aberration to any marked extent in a lens is that it will not give a sharp image. One of the uses of stops or diaphragms is to reduce spherical aberration, most lenses showing a great amount of this defect if worked with the full aperture of the glass.

Chromatic Aberration has, to all intents and purposes, been defined in the last chapter. It is the defect in a lens which causes it to bring light of different colors to focus at different points. The method of correcting it has also been given. Chromatic aberration to quite a marked degree was a very common defect with the older forms of photographic objectives, and it was generally necessary with these to make an allowance for it by racking the camera a short distance after focusing, or by allowing for the defect in the position given to the focusing glass; but modern lenses seldom show the defect to any appreciable extent.

Roundness of Field and Flatness of Field.—In treating of the formation of an image at the beginning of the chapter,

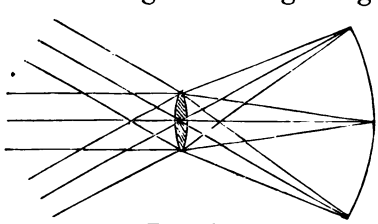


FIG. 18.

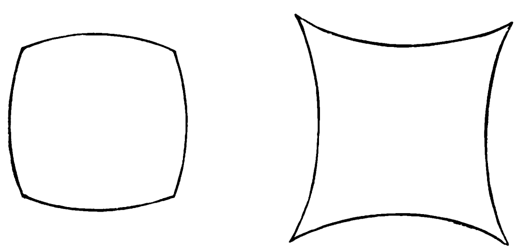
we assumed that a lens will bring rays or pencils of light to focus in a plane. As a matter of fact, however, no lens does so; but, on the contrary, every lens brings pencils to a focus

on a field more or less curved. A small bi-convex lens will bring them to focus very nearly on a sphere having the lens as center (see illustration).

One of the objects of making compound lenses is to reduce this curvature as much as may be, to make the pencils of light —as we use a flat plate—come to a focus as nearly as possible in a plane. This is never entirely effected, but in some lenses there is a pretty close approach to it. The nearer the approach the greater the flatness of field.

Astigmatism is a curious defect that can best be explained by supposing a case. We will suppose an object having cross lines to be focused—an old-fashioned window-frame, for example—the cross-bars near the center of the ground-glass will be shown quite sharp; those near the edge will appear tolerably sharp in one direction, but not in another. For example, the vertical bars will appear sharp, the horizontal greatly blurred. This is on account of astigmatism, a defect to be found in a marked degree, particularly in portrait lenses, where an attempt has been made to get greater flatness of field than is attainable without producing the other defect.

Distortion.—There are some lenses which do not render the object of quite the correct shape. Any straight lines



Outward Distortion. Inward Distortion.
FIG. 19.

near the margin of the plate are shown as slightly curved lines, unless they are running in the direction of the center of the image. There are two kinds of distortion, "outward" and "inward," or "barrel" and "pincushion." The cut illustrates in a greatly exaggerated way the two kinds of

distortion, the lines showing the nature of image that will be got from a square object.

There is a greatly exaggerated idea in the minds of most photographers as to the evils of distortion. But few lenses distort to any appreciable extent—only the single achromatic and the orthoscopic, in fact, and then only when a considerable angle of view is included, and when there are long straight lines near the margin of the subject. The fact is that, as a rule, the exaggerated perspective due to including too wide an angle (to be treated of presently) has generally been put down to distortion, although it is not really such.

These remarks apply to general photography. There are cases—as, for example, in the copying of plans and maps—where even the smallest amount of distortion would be fatal.

Angle of View.—This is the angle subtended by the view which the lens throws on to the plate. It would appear to be a simple enough matter to consider, but there are few subjects concerning which there is such inextricable confusion in the minds of most as of this one of angle of view; and, indeed, the writer finds some difficulty in making the matter plain.

The reason of the confusion is that, while it may be said that angle of view is entirely a function of the size of the plate and of the focal length of the lens, there are "wide angle" and "narrow angle" lenses which may be of the same focus. The following facts may first be stated: (*a*) All lenses of the same focal length include the same angle;* (*b*) the size of plate remaining the same, different angles are included only by lenses of different foci, the shorter the focus † the wider the angle included; (*c*) the focal length remaining the same, the amount of angle included by different lenses can vary only by the use of different sized plates—the larger the plate the greater the angle included.

Perhaps I shall make myself clear by taking definite examples. We may say, then (*a*), all lenses of 10 inches focal length

* This statement is not mathematically correct, if lenses which give distortion be considered. It is, however, very nearly so even with them.

† Strictly speaking, a focus is a point; but the word is so frequently used to denote "focal length"—already described—that I use it in this sense.

include the same angle on a plate 10 x 8 inches, whether they be called wide or narrow angle, so long as they will cover the plate at all; (*b*) with a plate 10 x 8 we can only take in greater or less angle by using lenses of less or greater focal length —a lens of 8 inches focus taking in, for example, a larger angle than one of 12 inches, even although the latter might be called a "wide-angle lens;" (*c*) with all lenses of 10 inches length we can vary the angle only by using larger or smaller plates, the larger the plate the greater the angle—thus, a lens of 10 inches focus includes a wider angle on a 12 x 10 inch plate than one on a 10 x 8 inch plate.

What, then, it may be asked, is the meaning of a "wide-angle lens?" If the question is one purely of focal length and size of plate, a lens is wide or narrow angle entirely according as it is used. This is quite true in so much that any lens includes a wider or narrower angle according to the size of plate that it is used with; but there are many lenses which will not cover a plate large in proportion to their focal length at all, so that they cannot be used to include a wide angle. A wide angle lens is, then, simply one that may be used with a plate large in proportion to its focal length. To take a definite example, a portrait lens of 7 inches focal length will probably not cover a plate $6\frac{1}{2}$ x $4\frac{3}{4}$. If the attempt be made with it, it will be found that the corners of the plate are not covered at all; or, at the best, that the definition at the corners is very poor. There are, on the other hand, some lenses of 7 inches focus which will cover, quite sharply, a plate 12 x 10 inches. The former is a narrow angle lens, the latter a wide angle. It is impossible to draw any sharp line between narrow and wide-angle lenses, but, as a rule, it may be said that a lens which will cover a plate whose diagonal is equal to the focal length is a lens of moderate angle; one which will, if required, cover a larger plate is one of wide angle; one which will not cover a plate so large is one of narrow angle.

Wide-angle lenses are very useful when it is impossible to get far away from the object to be photographed—as, for example, in much architectural work. They must, of course,

for such work, be used with a plate large in proportion to the focal length, or—the size of the plate being fixed—a lens of comparatively short focus must be used, otherwise, although the lens is of the wide-angle form, it will not include a wide angle.

When opticians first gave photographers wide-angle lenses, these latter inclined to make continual use of them on plates as large as they would cover, thereby including very wide angles of view; but the results were not satisfactory. A sort of exaggerated perspective was produced, objects in the picture not appearing to bear proper proportion to one another, especially those in the foreground appearing to be very large. The defect is not really distortion, but is due to taking a picture which, to be seen as a correct representation of the subject, would have to be viewed from a point closer to it than any one would naturally select.

It is now becoming daily more evident that it is desirable to include only a moderate angle—except in those cases already mentioned, where it is not possible to get far enough away from the object to do so without losing much that we desire to have in the picture. General opinion appears to be in favor of lenses of about the focal length of the diagonal of the plate for general landscape work, about one and a half times the diagonal for portrait work.

Depth of Focus.—In discussing the property, or various properties, of lenses to which the above name has been given, we get on a subject which has perhaps led to more discussion and difference of opinion than has almost any other which relates to photographic optics. No quite satisfactory definition has ever been given of depth of focus, and perhaps none such is to be found. I shall, therefore, explain generally what is meant by the term.

The very first time that the photographer focuses any object at a moderate distance from the camera he will perceive—if the opening of his lens is tolerably large—that when he adjusts the distance between the lens and the ground glass so that one particular object produces an image quite sharp, objects farther from or nearer to the camera produce images which are not

sharp. It will be found that if different lenses are used, or if different diameters of stops be tried, the result will be that the lack of sharpness of the different objects nearer and farther from the camera than that which is sharpest, varies, till, with a very small stop, we may have all objects apparently quite sharp. This property of making objects at different distances from the camera appear equally sharp is called depth of focus. The difficulties in the way of accepting the term as one having any precise scientific meaning are as follows: It is, in the first place, impossible to make objects at different distances from the lens mathematically equally sharp. There is always some object which is in the sharpest definition, or some position in which, were there an object, it would be in the sharpest definition—and objects at all different distances, however near the first-mentioned, will be less sharply defined. The manner in which the reduction of the size of a stop increases the sharpness of the image of objects before or in front of the distance of best definition is shown in the accompanying cut. A here is a lens, C is a point of an object which

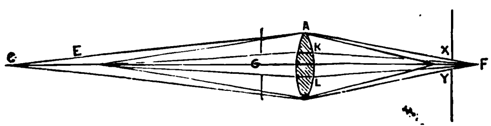


FIG. 20.

will be focused on the plane B D, representing the surface of the ground glass when we focus for C. E is the position of a point of an object nearer the lens. This point being nearer will throw off light which comes to a focus behind the plane B D,* say F. On the plane of the ground glass the point E will, therefore, be represented by a disk of the diameter of the whole pencil of light which has passed through the lens, as that pencil strikes the ground glass—that is to say, of the diameter represented by $x\ y$ on the sketch. It is evident that by introducing a stop as shown at G we reduce the diameter

* It is unnecessary to give all details as to why this is so. Those who have understood the explanations about prisms will readily understand how it is. Those who have not understood these explanations can certainly not be made to understand the question at present being treated by any further explanation that the writer can give.

of the whole pencil of light which passes through the lens, both at the lens and anywhere on its course behind the stop. We therefore notice it at the plane B D. The reduced pencil is shown by the lines *k* F, *l* F. We therefore reduce the diameter of the disk that represents the point E on the ground glass. It is, however, quite evident that we cannot reduce it to a mathematical point unless we have a stop of no diameter at all, which is impossible. We can, however, so far reduce it that it (the disk representing the point E) will appear to the eye no larger than the point (an actual mathematical point, if we leave spherical and chromatic aberration out of the question) representing the point C.

All the arguments that apply to the point E will also apply to a point further from the lens than C. For this reason, then —that although it is impossible to have objects at different distances from the lens in equally good focus * we may so far reduce the difference that it is not perceptible to the eye—it has been proposed to substitute the term depth of definition for that of depth of focus. The substitution would be an improvement, but the latter term has become so generally used, and in a loose sort of way understood, that I retain it here.

Depth of focus varies inversely as the focal length of lenses, and inversely as the aperture. It is therefore less the greater the focal length, and the greater the aperture.

Diffusion of focus is a term closely allied to *depth of focus*. There is a vast amount of uncertainty as to the precise meaning, or rather, perhaps, we should say, application of the term, mostly arising from the lack of precision in the term depth of focus. Again we shall try to get at a general idea of the meaning by explaning rather than attempting to define. Turning again to the last cut (Fig. 20), and considering that whereas the point C is represented by an actual point (the concessions mentioned above being for the time granted), and the point E being represented by a disk of considerable magnitude—in other words, an object at C being shown as perfectly

* I here leave out of the question the case of two objects, one at such distance behind, the other at such distance in front, of the plane of best definition, that they have both the same amounts of sharpness.

sharp, one at E as considerably lacking sharpness—it will be evident that the two must be in very great contrast. If, however, we deduct a certain amount from the sharpness of *both*, although we will reduce the definition of both, we shall also reduce the *contrast*, and the image of an object at E will (although actually worse defined than before) look sharper, because there is nowhere any absolutely sharp definition to show the want up by strong contrast. If the lens A possess *spherical aberration*, neither of the points C or E will be absolutely defined; and therefore the condition will be satisfied, for the point which is in worst definition not being thrown into strong contrast with another which is in excellent definition. An arrangement whereby spherical aberration could be produced at will in a lens was, I believe, first suggested by my esteemed friend, J. Traill Taylor, and the idea was first put into practice by the famous optician Dallmeyer. It is said of a lens in which it is possible to produce spherical aberration at will that it possesses a *diffusion* of focus arrangement. Such an arrangement is of use only in the cases where it is not possible to get depth of focus by the introduction of a small stop, as in the case of portrait lenses, where the small stop would, in certain circumstances, prolong the exposure to too great an extent.

The dispute about diffusion of focus is as to whether it does or does not actually increase depth of focus. It does not actually make any part of an image sharper; on the contrary, it makes every part less sharp; it therefore, say some, produces no increase in the depth of focus. The opponents of these, on the other hand, argue that as there *is* no actual depth of focus, as the whole question is one of definition as judged by the eye, an arrangement which makes the definition of objects at different distances *apparently* more equal does actually increase the depth of focus. The question is in reality purely one of terms, and where the terms cannot be strictly defined it is idle to argue one way or the other. I leave the reader free to take what view of the question he likes, a thing which he would probably do whether he were left free or not.

The rapidity of a lens is the measure of the time of exposure needed when it is used. Other things being equal, the rapidity is inverse as the exposure required. It is directly as the amount of light which the lens allows to pass through it. I shall have more to say on this subject in another chapter.

CHAPTER V.

ON PHOTOGRAPHIC LENSES.

WE now come to a consideration of the actual forms of lenses used in practice. I illustrate these, briefly describe them, and in each case point out what are the particular distinguishing qualities of the lens. It is impossible, however, as a rule, to go into the question of why any individual lens possesses particular qualities. For example, we cannot here discuss in detail why the portrait form of lens permits the use of a larger aperture than the "rapid symmetrical," as to do so would alone require a treatise involving advanced mathematics. The reader must, therefore, take it for granted that the lenses do possess the qualities attributed to them, and must—or ought to—thank those opticians who have worked out the various forms—often at the expense of almost inconceivable labor.

The Single Achromatic Lens.—While discussing the question of chromatic aberration and of achromatism, we gave a cut showing the section of the actual glass portions of three different forms of single lens. I now illustrate a single lens as mounted.

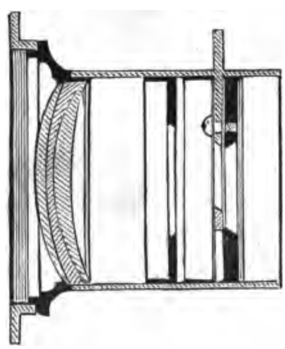


FIG. 21.

The single lens has certain advantages over all others. In the first place it is simple, and therefore comparatively cheap.

The simplicity also results in the fact that the light has to pass through only two surfaces, at which very little of it can be reflected—there is practically no reflection of light from two surfaces of glass cemented together—and this results in a certain crispness of image greater than can be got by any other lens.

On the other hand, the lens is comparatively slow, includes only a moderate angle, and distorts to a certain extent. The older forms of single lens were very slow, working with maximum apertures as small as f and even smaller. They also included only very narrow angles. Some considerable time ago the construction of single lenses was improved so as to admit of a somewhat larger aperture. The two forms are shown in the cut intended to illustrate the method of achromatization. One optician secured, besides a larger aperture, a wide angle. Both lenses worked at about $\frac{f}{16}$. Recently the single lens was so far improved as to get an aperture of $\frac{f}{8}$—even with large lenses—giving definition good enough for some kinds of work (for large heads, for example), and giving good enough definition for any kind of work with an aperture of $\frac{f}{11}$. The lens made by the first-mentioned optician includes also a considerable angle when desired, and the writer considers both a real advance in the matter of lens construction.

The single lens always gives some distortion of the "barrel" form if the stop be placed in front—as it almost always is—of the "pincushion" form if it be placed behind. This distortion is so slight as to be quite unnoticeable when there are no straight lines in the picture near the margin, and in all cases when only a narrow angle is included, except the one case of copying such things as maps. The writer considers it advisable to use the single lens whenever it is possible to do so; that is to say, when great rapidity is no object; when it is not needed to include a very wide angle, and when a small amount of distortion is not of consequence. It may be used for the greater part of landscape work, and for portraiture when it comes to a case of very large sizes, as then it is impossible to use a large aperture, even if the lens possess it, on account of the want of depth of focus due to the great focal length that

must be used for large portraits. The distortion is by no means such as to show with portraits.

The Rapid Landscape Type of Lens.—This is the name given to a type of lens designed to overcome two of the objections that there are made to the single lens—or were at any rate at the time when the "rapid" form of lens was invented—namely, the slowness and the distortion. The lens was the result of the combined work of Drs. Monkhoven and Steinheil. We illustrate it here. It will be seen that the lens

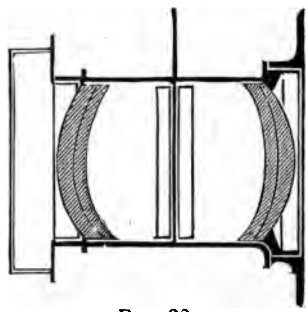


FIG. 22.

may be said to resemble two of the lenses of the kind last described—the single achromatic I mean, not the special form of single achromatic with three lenses that has just been illustrated—placed face to face. Each singly would distort, but in a direction opposite to the other. The two distortions therefore correct one another, and an image absolutely free from distortion results. Hence, the names commonly adopted, "rapid rectilinear," "rapid symmetrical," and so on. The form, besides giving no distortion, permits of a comparatively large aperture, which means increased speed. In fact, a stop the whole aperture of the lenses may generally be used. For this reason this form of lens is frequently called "aplanatic." The aperture common until quite lately was such as $\frac{f}{8}$ to $\frac{f}{10}$. Of late years, however, although there has been no radical change in the form of the lens, improvements in manufacture and in the quality of optical glass obtainable have enabled the aperture to be increased considerably. Thus, Suter, of Basle, issues a lens with an aperture greater than $\frac{f}{6}$, and indeed

Voigtlander and Dallmeyer, while adhering to the form of construction, have contrived to increase the aperture to $\frac{f}{4}$, or even a little more, thereby bringing the lens under the head of portrait lenses—to be presently considered.

The American Form of Rapid Landscape Lens.—As has been said, although European opticians have, by care in workmanship and by the adoption of denser glass, been able to increase the aperture of their rapid landscape lenses, the old construction of Steinheil and Monkhoven has, for the most part, been adhered to. The only cases that I know of in which something entirely new has been struck out are those of the late Morrison, in America, who, some years ago, made a new departure in the construction of lenses, and of Steinheil, who has recently constructed a lens entirely different from anything that has been in use before. I here illustrate Morrison's lens.

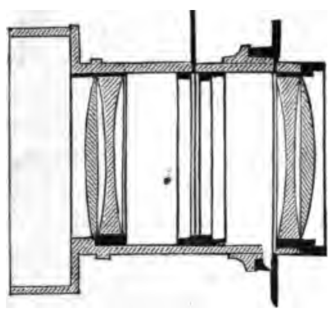


FIG. 23.

It will be seen that the lenses of each combination are separated from each other by some little difference. By this arrangement the necessary corrections are gained without the necessity for using the deep curves which are seen in the older Steinheil form, and which involved considerable expense in glass.

The writer cannot speak of the performance of the Morrison lens from personal experience, but as it is vouched for by so good an authority as J. Traill Taylor, he has no doubt it is excellent.

The New Steinheil Antiplanatic.—An illustration of this lens is here given.

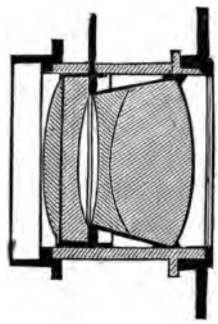


FIG. 24.

It will be seen that the construction is quite different from anything that we have yet considered. I have had no great opportunity of practically testing this lens, having, in fact, only once made a trial of it. It is scarcely fair to judge a lens from a single trial made with a single sample, however much care be used in the experiments, and I therefore stand ready to be corrected when I say that from that trial I could find no great advantage in the new over the older form of lens by the same maker. The maximum aperture was larger, it is true (about $\frac{f}{6}$), than that generally given to the older forms of lens by Steinheil himself; but not larger than that recently given by some other opticians, and the field appeared to be rounder.

Uses of the Rapid Landscape Types of Lenses.—It may probably be said, without much fear of contradiction, that the rapid landscape is the best all-round lens that can be got. If a photographer can afford to have only one lens, he will probably do better to have a rapid landscape than to have any other form. The angle included is large enough for all except very special cases; there is a complete absence of distortion, and the rapidity is such that instantaneous work may be done with the lens better than with any other landscape lens, while it is also well suited to portraiture. For the last-mentioned kind of work the more modern lenses, with

considerable apertures, will of course be found to be the best. Indeed, I do not hesitate to predict that these lenses will, before long, all but oust the portrait lens.

The Rectilinear Landscape Lens.—It is probably due to the great increase of the practice of photography that has arisen since the introduction of dry plates that the past few years have been prolific in the production of new forms of photographic lenses. Among the most remarkable of these is the lens just mentioned above. This lens may be described as half-way between the single lens and the rapid rectilinear. By an inspection of the cut it will be seen that although it really consists of two separate lenses, these are both at the same side of the diaphragm; that in fact they take

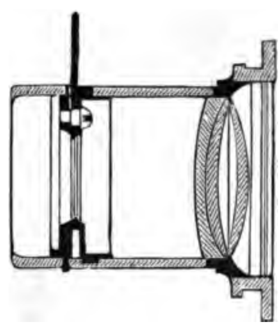


FIG. 25.

the place of the single combination in the "single landscape lens." The lens is useful for all work that a rapid rectilinear can be used for with moderate aperture, it gives better marginal illumination, and more equal lighting from the center to the edges of the plate. It has been claimed for it that it has the advantages of the old form of single lens, throwing a smaller amount of reflected light into the camera. This is a claim that the present writer cannot admit, as he has already explained. The angle included is moderate, but is sufficient for most work where a very wide angle does not need to be included. The lens can be specially recommended for copying.

Wide Angle Lenses.—The term "wide angle" has been applied to some modern forms of single lenses because these

include a considerable wider angle than was included by the older forms of single lenses, but to these the writer does not here refer. He refers to double combination forms of lens, whereby a very great angle—often as much as 90 degrees on the diagonal of the plate—may be got. The reader has already been warned against using such lenses to include the full angle that they will take in, except in such cases as is unavoidable, the result being a false perspective.

In England there have been practically only two forms of wide angle lens in use during many years. The first of these is the Dallmeyer form, which is illustrated here.

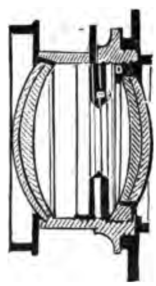


FIG. 26.

It will be seen that there is great similarity between it and the rapid symmetrical form of lens, the chief difference being that the combinations are placed closer together in the wide angle form.

The next lens that I illustrate is Ross's portable symmetrical. In this certain corrections are secured by thickening the glass. The lenses are of comparatively small diameter, hence the term "portable." They are, moreover, so constructed that a number of them will screw into the same flange. These facts make the portable symmetrical one of the most popular lenses in England for general landscape work, the lens for such work being used to cover a plate much smaller than the largest it will cover. Thus a portable symmetrical of 10 inch focus which will cover a plate 13 x 11 inches makes a capital lens for ordinary work on any plate from $6\frac{1}{2}$ x $4\frac{3}{4}$ to $8\frac{1}{2}$ x $6\frac{1}{2}$.

These lenses—and, indeed, nearly all wide-angle rectilinear lenses—are particularly well adapted for working as a series, or, as it is commonly said, as a "battery," by which is meant that their form is such that, working any particular size of

FIG. 27.

plate, it is easy to take out a set of three or four of such lenses as will permit any angle to be included that may be desired. As an example, for a whole plate ($8\frac{1}{2} \times 6\frac{1}{2}$) a battery of so-called "wide-angle" lenses might consist of four of the following focal lengths, 6 inches, 8 inches, 10 inches, 12 inches.

We next come to the wide-angle lens of Morrison, which I illustrate. It will be seen that the inventor has, with charac-

FIG. 28.

teristic boldness, departed entirely from all common forms, inasmuch as one element of the lens is without achromatization at all. Presumably the other is over-corrected. The writer has not had practical experience of this lens, but again takes the word of Mr. Taylor, who pronounces its performance excellent.

Uses of Wide-Angle Lenses.—I have already spoken of the objection to the use of wide-angle lenses to include all the angle they will include except when it is unavoidable. I should add that when they are so used it is always necessary to insert a small stop, and that therefore the lenses are slow.

For ordinary landscape work any of the forms of wide-angle lens described is excellent if it be used for a plate of moderate size only, so that but a moderate angle is included. They all have the advantage that they give no distortion, even when the widest angle is included. For this reason they are particularly well adapted to architectural work. The maximum aperture of wide angle lenses is, as a rule, about $\frac{f}{16}$; they must, therefore, be ranked as slow lenses. Indeed, modern single lenses have shot ahead of them in the matter of rapidity.

The Portrait Lens.—This lens may be considered to be in great measure the crowning triumph of the photographic optician. It is true that in the present day it is of comparatively little use, but this does not make the credit of having worked it out when it was a great desideratum the less.

The object in the portrait lens has been to get the greatest rapidity possible. Other qualities have certainly to some extent been sacrificed to this one of rapidity, but still it is a lens wonderfully well adapted for the purpose for which it was designed—namely, the production of portraits pure and simple on films which, according to our modern ideas, were very slow. With an enormous aperture, the portrait lens gives definition of a very high quality on a small plate. The angle included is small—full aperture being used, and fine definition being required to the edge of the plate—very small, indeed. Still, this is not altogether a disadvantage, as a quality has some use which restrains photographers in their tendency to include too wide an angle in portraiture—in other words, to use lenses of too short focus. The greatest defect in the portrait lens is the want of depth of focus, a defect which a consideration of what we have said under the head of depth of focus will be seen to be inherent to a lens with a very large aperture.

The lens illustrated here is the Petzval form of portrait lens, which was, until quite recently—unless we consider Dall-

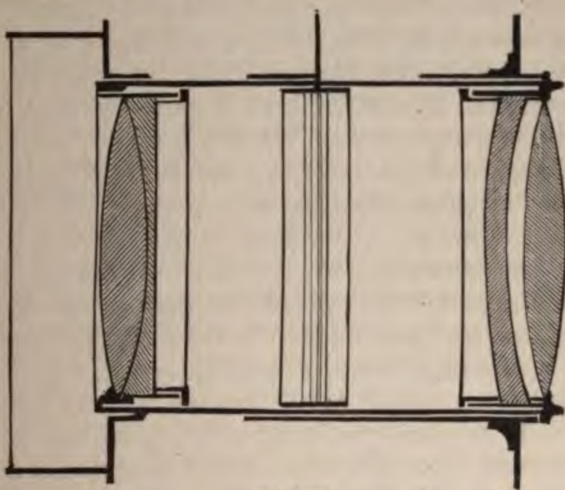


FIG. 29.

meyer's diffusion of focus lens, to be hereafter described—the instrument universally used for portraiture.

Dallmeyer's Diffusion of Focus Portrait Lens.—The use of *diffusion of focus* has been so far pointed out under that heading that it is enough here to further point out that it is

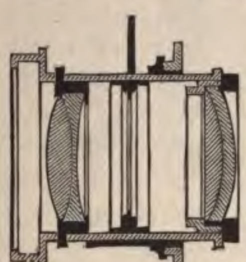


FIG. 30.

more likely to be of use in the case of the portrait lens than in that of any other, and to illustrate the very ingenious arrangement whereby Dallmeyer has contrived to construct a lens in which it is optional to have it or not.

It will be seen that in this lens the positions of the two glasses forming the posterior element or combination is reversed. Further than this, they are so arranged that the posterior lens can have its position, with regard to the other of the posterior element, altered without disturbing the rest of the instrument. The adjustment is made by screwing the lens backwards or forwards. When it is screwed home as far as it will go, spherical aberration is reduced to a minimum; as it is unscrewed spherical aberration in increased till the desired degree of "diffusion" is obtained.

The New Steinheil Portrait Lens.—Recently Steinheil introduced a portrait lens which is as great a departure from anything that had been done before as is his rapid landscape lens. I here give an illustration of this lens.

The writer has himself had no experience of the working of this lens; he has, however, heard it well spoken of. The following is what Debenham says of it: "Astigmatism has been wonderfully got rid of, but there is an amount of curvature of field which renders it unfit for working on a large field, for

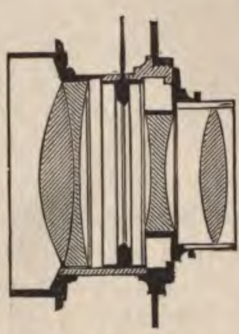


FIG. 31.

which, however, it is not intended. The construction of the lens is such that the illumination of the plate is more even than with the ordinary form of portrait lens."

Voigtlander's and Dallmeyer's New Portrait Lens.—This lens, which was introduced as lately as the end of 1886, has already been mentioned. It is simply a lens of the type of

the common rapid symmetrical or rapid rectilinear—Steinheil's old aplanatic, in fact—but with the aperture greatly increased. This involves no new principle, but is nevertheless a great triumph of optical skill. It is unnecessary to illustrate the lens here, as the general form of it will be gathered by looking at the cut, showing the lenses just mentioned.

The chief advantages of the lens over those of the Petzval form is that the back combination being cemented as well as the front, there are two fewer reflecting surfaces. It may be well here to point out that the disadvantage of reflecting surfaces does not lie in the actual loss of light, which is trifling, but in the fact that a part of the light so lost is thrown into the camera in the form of diffused light, tending to reduce the crispness of the image, if not actually to produce fog, also distinctly reducing the latitude of exposure. A portion of all light reflected from all surfaces except the first which the light strikes is re-reflected from all surfaces anterior to that surface, and finds its way—or part of it does—into the camera in the form of diffused light.

The Uses of the Portrait Lens.—The portrait lens should only be used where shortness of exposure is the first object. Its usefulness has naturally been reduced as films have become more rapid, and still more as the rapidity of the landscape form of lens has been increased, till it may be said that the portrait lens has almost ceased to be a necessity for any kind of work; specially is this to be said of large sized lenses. With these the depth of focus, if full aperture be used, is so slight that they can scarcely be used except with a stop which makes them as slow as a rapid landscape lens of modern type, and even slower, in which case the landscape lens would be found to be a superior instrument. Still there are circumstances in which a moderate sized portrait lens—say one of 12-inch focus or so—is very useful. Such a lens is really about the largest that can be used with full aperture with any freedom. It will serve for plates of any size up to 6½ x 4¾, and will be found useful in the studio in very dull weather, or at all times when portraiture is attempted in an ordinary room.

It should be said that there are cases where a portrait lens may be useful for instantaneous work. For most instantaneous work rapid landscape lenses are quite rapid enough, but there are cases where it is desirable to give "instantaneous" exposures with dull subjects, or where the exposures have to be extraordinarily short. The best example of the latter is the marvellous work done by Muybridge in photographing animals in motion, the exposures being said to be as short $\frac{1}{5000}$ part of a second. For such work the most rapid portrait lens will not be found to be too quick. It will, however, be found impossible to use only small plates and short focus lenses. Probably for work of the kinds mentioned the best results will be got with "lantern size plates" ($3\frac{1}{4}$ inch by $3\frac{1}{4}$ inch) and a lens of about 6 inches focus.

The common aperture of the portrait lens is f, or somewhat over. Specially rapid lenses have been made with apertures nearly as great as f. I am not aware that this aperture has actually been reached, but there could be little doubt that, were opticians of the present day to set their minds on such a lens, it could be produced. The time has, however, passed when it would be of any use.

The Group or Universal Lens.—A lens of the portrait form, but of about half the rapidity of the ordinary portrait lens, has been greatly used, where a lens of rapidity between the portrait and the rapid landscape was desired. It was sold under such names as the above. Since the recent increase in the rapidity of rapid landscape lenses, the group lens has in great measure lost its place as a really useful instrument, and it will probably before long become obsolete.

The Use of One of the Combinations of a Doublet Lens.—In the case of most of the lenses of the "rapid" or "wide angle" type, either the back or the front combination may be used alone, the other being increased, where a single lens of long focus will be of use, where the lens is "symmetrical" in the sense of having the two combinations similar, the focal length of one combination will be about twice that of the two. As the combinations of a doublet are not specially constructed to be used as single lenses, it is generally

necessary to stop them down to a very small aperture, [illegible] or so. With such apertures, however, they give excellent results.

Obsolete Forms of Lenses.—There are many forms of lenses which took the place of the "rapid landscape" and the "wide-angle landscape" lenses of the present day before these latter were invented. They have been superseded, because their performance was inferior to that of modern lenses in some respects. Most of them scarcely require notice here. There are two forms, however, of which something should be said; these are frequently to be purchased second-hand, and very cheaply. The photographer who cannot afford expensive lenses will often find a most useful instrument in one of these if it be by a good maker.

The Orthoscopic.—This lens is the twin brother of the Petzval portrait lens, having been invented at the same time by the same distinguished scientist. It was invented at a time

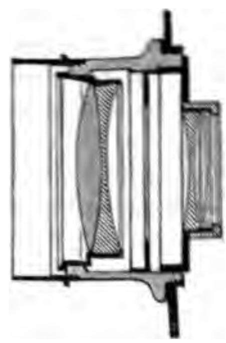


FIG. 32.

when the single achromatic lens was the only one in use for landscapes. It gave a considerably increased aperture (about $\frac{f}{10}$, considered beyond the powers of a single lens in those days), and improved flatness of field. The orthoscopic gives distortion of the inward or "pin-cushion" nature. The lens has the advantage that the focus being measured from a point in front of the anterior element, a lens of comparatively long focus can be used with a camera racking out to a given amount.

There are those to be found who still predict a great future for the orthoscopic, when some modern optician of eminence chooses to take it up again.

The Triplet.—The triplet lens is interesting as the first form of non-distorting lens which was at all generally used.

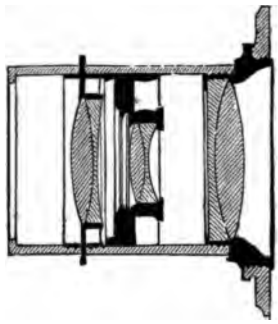


FIG. 33.

It may be said also to have been the first lens of the "rapid landscape" type, as it worked at an aperture of $\frac{f}{10}$, or something approaching that. The performance of this lens is, in spite of the drawback of the six reflecting surfaces, excellent. The angle included is only moderate, but the definition is of the highest order and the field is very flat. There are some who, even at this present day, prefer the triplet lens to any other for copying.

CHAPTER VI.

MEASURING THE FOCUS AND APERTURE OF LENSES—ESTIMATING THE RAPIDITY—TESTING LENSES.

Comparing the Rapidity of Lenses.—It has already been mentioned that the rapidity of a lens is determined by the aperture and the focal length. It is, in fact, decided by the relation of the former to the latter. Thus, the focal length is divided by the aperture, and it is common to state the result in the form $\frac{f}{4}$, $\frac{f}{10}$, $\frac{f}{22}$, etc., these expressions meaning that the apertures are respectively $\frac{1}{4}$, $\frac{1}{10}$, and $\frac{1}{22}$ of the focal lengths. ***The relative rapidities are directly as the squares of their fractions; the exposures required are directly as the squares of the denominations.***

Thus squaring the fractions, the rapidities of the lenses represented by them will be relatively $\frac{1}{16}$, $\frac{1}{100}$, $\frac{1}{484}$. In practice, however, it is customary, in comparing lenses, to compare the exposures required by them rather than the relative rapidity. The exposures required by our three hypothetical apertures, whether they belong to the same or to different lenses, will be in the square of the denominators of the fractions, namely as 16, 100, and 484, or dividing all by 16, and leaving fractional parts out of consideration as 1, 6, and 30. To put this result in words, if we have three lenses with apertures respectively one-fourth, one-tenth, and one twenty-second of the focal length, or if the same lens have three different stops of these apertures, the exposures required for the second and third apertures will be respectively six and thirty seconds if that for the first is one second.

Some years ago, the Photographic Society of Great Britain proposed that a certain angular aperture of lens (aperture in terms of focal length) should be taken as a standard, and that all other apertures should be compared with this, the other apertures having attached to them figures representing the

exposure that would be required with them, when that required with the standard or unit was 1. Thus a stop requiring twice the exposure of the standard would be numbered 2, one requiring three times 3, and so on.

The standard taken was f. This was called No. 1, and it was advised that stops be cut to such diameters that each one would need twice the exposure of that which went before it. The numbers would then run: 1, 2, 4, 8, 16, 32, 64, 128, 256, etc., and these numbers are generally termed the U. S. number or "universal standard" numbers. Thus if we speak of a stop as No. 8. U. S., we mean that it is a stop with which will be needed eight times as long an exposure as with a lens working at f.

The diameter of No. 1 aperture for any lens is got simply by dividing the focal length by 4. That of No. 2 stop is got by dividing the diameter of No. 1 by $\sqrt{2}$, or by dividing the focal length by $4 \times \sqrt{2}$, which is 5.657. These two diameters having been decided, those of the stops Nos. 4, 8, 16, etc., are easily got, No. 4 needing simply half the diameter of No. 1, No. 5 half the diameter of No. 2, and so on. If a lens has not so large an aperture as $\frac{f}{4}$, there is of course no aperture as large as No. 1, and the numbers begin at whichever of the standard apertures happens to coincide with that of the lens. Thus rapid landscape lenses generally have a maximum aperture of No. 4. What are called group lenses (really slow portrait lenses) No. 2, with angle lenses No. 16, etc. Some lenses have maximum apertures larger than No. 1. These are represented by fractions as No. $\frac{1}{2}$, etc.

It does not by any means always happen that the maximum aperture of a lens coincides with any of the standard numbers. In such case it is inadvisable to lose any of the available speed of the lens by reducing the aperture by a fixed stop merely to make the full aperture representable by a whole number, and a special number is got by squaring the denominator of the fraction representing the aperture in terms of the focal length, and dividing by 16. Thus if a lens have a maximum aperture of $\frac{f}{4}$, we take $\frac{5^2}{16} = \frac{25}{16} = 1.562$. We would in this case stamp on the mount of the lens 1.562, expressing the fact that

with this lens 1.562 times as much exposure was needed as with one working at $\frac{f}{4}$, or about half as long again.

Recently Mr. Dallmeyer has suggested that the standard $\frac{f}{4}$ should be replaced by that $\frac{f}{\sqrt{}}$. The result of the adoption of this standard would be to simplify some calculations in connection with lenses, and to complicate others. The writer is not prepared to say whether the general result would be complication or simplification, but he has little hesitation in expressing the opinion that any slight simplification that might arise from adopting the proposed new system would by no means compensate for the disadvantage arising from the disturbance of a system which has already taken considerable hold with the photographic public.

Measuring the Focal Length of Lenses.—It is evident that before we can enter on any of the calculations just mentioned, we must have some way of measuring the focal length and apertures of lenses.

Let us say at once that for many purposes it is sufficient, in the case of simple lenses, the ordinary forms of single achromatic lenses, double combination wide angle lenses, and portrait lenses, to proceed as follows: Focus a distant object, or better—say the sun—in the case of the single lens the distance between the front surface of the lens and the ground glass is measured. In the other cases the distance between the diaphragm and the ground glass.

For many purposes and with the lens of simple construction, the measurements thus got will be accurate enough; but they will not be at all accurate with some other forms of lens—notably the orthoscopic and Dallmeyer's new forms of lenses and in no case is it really precise. The following [illegible] are very popular for determining, with a limited degree of accuracy, the focal length of a lens.

In front of the camera is placed a [illegible] convenient object. The distance between the front [illegible] lens, and that between the lens and the ground glass [illegible] adjusted that the image on the ground glass is of [illegible] size as the object. The distance from the [illegible]

ground glass is now measured. This, divided by 4, is the equivalent focal length.

Example.—When we draw out a camera till the image on ground glass is equal in size to the object, we find that the distance from the object to the ground glass is 32 inches. One-quarter of this, or 8 inches, is the equivalent focus.

The following method may be adopted when the camera will not rack out to twice the focal length of the lens. It is capable of giving very precise results, but requires a slight knowledge of mathematics.

d = distance from object to ground glass when a near object is focused.

o = length of object focused (preferably a measuring rod).

i = length of the image of this rod on the ground glass.

F = lesser conjugate focus—that is to say, the distance between the point where the axes of pencils of light in the lens cross each other, and the ground glass when a near object is focused.

f = equivalent focus.

$$F = \frac{i \times d}{o + i}$$

$$f = \frac{F(d - F)}{d}$$

Example.—A 5-foot rod is focused. The length of the image on the ground glass is found to be 6 inches. The distance between the rod and the ground glass is found to be 10 feet 1 inch.

$$F = \frac{6 \text{ ins.} \times 10 \text{ ft. } 1 \text{ in.}}{5 \text{ ft. } 0 \text{ in.} + 6 \text{ ins.}} = \frac{6 \times 121}{60 + 6} = \frac{726}{66} = 11$$

$$f = \frac{11\,(12111-)}{12} = \frac{1210}{121} = 10$$

Equivalent focus therefore = 10 inches.

The methods just given are quite accurate enough for all practical photographic purposes, but even they are not mathematically precise. The following is a method which is (leaving out of consideration, of course, manipulative errors in measuring, etc.) absolutely correct.

An object, such as a foot-rule, is placed in front of the camera, and the latter is racked till the image is of precisely the same size as the object. The distance of extension of the camera is now carefully noted, and afterwards a distant object (say) the sun is focused. *The amount that it is necessary to rack in the camera to focus this distant object is the precise focal length.*

Example.—We so adjust the camera that the image on the ground glass of a foot-rule is precisely one foot long. We now take the camera and find that we have to rack it in $11\frac{3}{8}$ inches to get the image of a distant object sharp. The precise focal length of the lens is $11\frac{3}{8}$ inches. Various ways of accurately measuring the distance that the camera has to be racked will suggest themselves to the reader.

The following mechanical method, devised by the writer some six or seven years ago, is quite accurate. A very brightly lighted object is focused. Two conspicuous distant objects, one near each end of the ground glass—or at any rate at some distance from each other—are observed, and the precise distance between them is measured either by a foot-rule, or better, with a pair of dividers. The cells of the lens are now unscrewed, and into the diaphragm slit is inserted a diaphragm with an opening of about $\frac{1}{32}$ of an inch diameter, or in the case of short focus lenses even less than this may be made for the purpose of blackened cardboard. An image will be got on the ground glass, which will certainly not be very brilliant, but will permit of the measurement of the distance of the two objects. The lens tube is racked in or out till this distance is precisely what it was before the lenses were unscrewed. The distance between the temporary diaphragm and the ground glass is the focal length of the lens.

To Measure the Aperture of a Lens.—For most practical purposes it is sufficiently accurate to measure, for maximum apertures, the fixed stop; if this be smaller in diameter than any of the combinations, to measure the diameter of the closer opening of the smallest combination if this be smaller than any fixed stop; for other apertures the actual diameter of the stops.

These measurements are, indeed, strictly accurate in the following cases: In that of the single lens, when the diameter of the stop is the precise aperture, and in lenses of the rapid landscape or portrait type, where the fixed stop is as large as the front lens, and when this latter is not larger than the back combinations. In this case the diameter of the front lens is the precise aperture.

In other cases, if we want to be strictly accurate, allowance must be made for the condensation of the light by the first combination, in estimating the diameters of apertures—that is to say, for the purpose of comparing exposures. Of course in the merely mechanical sense the aperture is always the precise diameter of the stop. To explain. If a portrait lens having inserted a stop 1 inch in diameter, the aperture of the lens is in a mechanical sense precisely 1 inch; but for the purpose of comparing exposures, we must take into consideration the fact that before the light has reached the stop it has been very considerably condensed by the front combination, and that, therefore, the stop lets through more light than it would were it in front of the lens, and is, in fact, equivalent to a stop of somewhat more than 1 inch in diameter.

There are two methods of making the necessary allowance —one a mechanical, the other a mathematical. We give the mechanical method first.

A distant object is focused, and, without changing the adjustment of the camera, the ground glass is replaced by a piece of cardboard with a small hole, little larger than a pinhole, in the middle of it. The camera is then carried into a dark room. A little powder is "puffed" on to the face of the front lens, and a lighted candle is held behind the hole in the cardboard. There will now appear a circle of light on the surface of the front lens. This surface is somewhat larger than the stop, and is the value of its diameter, after allowing for the converging effect of the front lens.

The mathematical plan is as follows:

d = Actual diameter of stop.

D = Aperture value (*i. e.*, the diameter after allowing for the condensation of the light by the front lens).

f = Focus of front combinations.

l = Distance between the plane of stop and the center of the first combination (by center is meant half-way between the anterior and posterior surfaces).

$$d = \mathrm{D} \times \frac{f}{f-l} \qquad \mathrm{D} = d \times \frac{f-l}{f}$$

Example.—We have a portrait lens of 13 inches equivalent focus. We find that the focal length of the front combination is 20 inches. The distance between the center of the front combination and the plane of the stops is 3 inches. We want to know the value of a stop of 2 inches actual diameter, and also to find what actual diameter we should give to a stop to have a value of $3\frac{1}{4}$ inches, so as to stand for No. 1 or $\frac{f}{4}$ of the lens.

In the first case—

d = 2 inches.

f = 20 inches.

l = 3 inches.

Therefore—

$$\mathrm{D} = 2 \times \frac{20}{20-3} = 2 \times \frac{20}{17} = 2{\cdot}353 = 2\tfrac{3}{8} \text{ inches, very nearly.}$$

That is to say, we give to the stop of 2 inches in diameter the value of one $2\frac{3}{8}$ inches diameter.

It is to be observed that if this estimation ever give a diameter larger than the front combination of any lens of the symmetrical type, it means that the stop is not of any use, and that the actual maximum aperture is the diameter of the front element.

In the second case—

F = $3\frac{1}{4}$ inches.

f = 20 inches.

l = 3 inches.

Therefore—

$$d = 3\tfrac{1}{4} \times \frac{20-3}{20} = 3.25 \times \frac{17}{20} = 2.762$$

= the smallest trifle over $2\frac{3}{4}$ inches. We shall, therefore, in

the case of one portrait lens of 13 inches focal length, make the No. 1 stop not $3\frac{1}{4}$ inches diameter, but $2\frac{3}{4}$ inches.

If it be desired to cut the stops with great precision, using a table of the diameters of U. S. stops for different focal lengths, such as I give in my "Modern Photography," it will be necessary to make a correction for each one in the manner just described—practically only for the first two, as all others can be got by dividing each of the corrected results by 2, 4, and so on. But probably an easier way will be to assume a shorter focus, and to look up in the tables the stops, as if they were for a lens of this shorter focus. The method of making the necessary allowance is as follows:

$F =$ The equivalent focus of the lens.

$f =$ The focus of the front combination.

$l =$ The distance between the center of the front combination and the plane of the stop.

$A =$ Assumed focus.

$$A = F \times \frac{f-l}{f}$$

Example.—In the actual case that we have supposed, of a lens of 13 inches equivalent focus, whose front combination is of 20 inches focus, and in which the distance between the plane of the stop and the center of the front combination is 3 inches.

$$A = 13 \times \frac{20-3}{20} = 13 \times \frac{17}{20} = 11.05$$

or we may say 11 inches.

We shall therefore cut our stops as for a lens of 11 inches focus in place of one of 13 inches.

Testing Lenses.—To perform a thorough test of a lens, to be able by examining it to say at once what is its standard of excellence, and, if it have faults, what precisely these faults are, is a thing requiring great skill, much practice, and some knowledge of optics; but no very great practice is needed to judge fairly well of the properties of a lens, and it is of great importance that the photographer should be able to do so, especially if he have a tendency to pick up second-hand

lenses. Lenses offered second-hand by all except recognized dealers in photographic goods are, for the most, rubbish; but if the photographer know how to tell a good lens from a bad, he may occasionally pick up an excellent instrument for a mere trifle.

We shall give first a few tests, of which it may be said that if any one of them give an unsatisfactory result, the lens should be at once condemned. We shall then give the method of comparing two lenses. It is only by comparing a number of lenses with each other that the photographer can learn how actually to judge of a lens, as till he has made such comparisons he cannot be expected to know what to look out for.

Focus.—The first thing is to discover roughly the focal length of the lens. The methods of doing this have already been described.

Aperture.—After the focal length has been determined, it is necessary to observe the maximum aperture of the lens, as probably two out of three lenses offered for sale, say, by pawnbrokers, may be condemned on this point alone. In describing different forms of lenses I have given for each form the maximum aperture at which the lens can be expected to work. *If a lens be offered for sale with an aperture much under this it may be assumed at once that the lens is defective,* the aperture having been reduced to hide the defect—probably imperfect correction for spherical aberration—so far as possible. For example, a portrait lens with actual lenses of aperture $\frac{f}{4}$, but with a fixed stop reducing this aperture to $\frac{f}{6}$ or ^{f}, may at once be rejected. The same may be said of a "rapid landscape" lens with aperture reduced by a fixed stop to $\overline{11}$ or $\overline{12}$.

Definition.—The next step is to test the defining power of the lens with full aperture. A camera with very fine ground glass should be used, and the image should be magnified with one of the eyepieces commonly used for focusing. Some clearly defined object is selected—a steeple clock is an excellent one if the disk be of a light color. This is focused in the center of the plate. The image should appear quite sharp under the magnifier. At the maximum apertures mentioned

in the last chapter, a lens is at once to be condemned if it show any want of sharpness in the center of the plate; to be strictly correct, I should say in the axis of the lens under the ordinary focusing magnifier. A really good lens will show no falling off under a magnifying power ten times that of the eyepiece commonly used by photographers.

Correction for Chemical Rays.—The lens having proved satisfactory in the two points just mentioned, we may proceed to test it for the coincidence of chemical and visual focus. It may be here mentioned that appreciable want of this coincidence is not a very common fault even among second-rate lenses of the present day; but with older lenses, in other respects of the very highest quality, it is by no means uncommon. Indeed, some of the best opticians were, at one time, in the habit of purposely leaving an appreciable residuum of chromatic aberration, because more perfect correction of certain other defects could then be made. It was in those days customary to allow for this by either having the plane of the plate in the dark slide a little different from that of the ground glass, by racking the lens a measured distance after focusing, or by introducing during the time of focusing a supplementary lens of very long focus, so as to shorten the focal length of the whole combination by the precise amount due to the want of correction. Such things would not be put up with at the present day, and a lens which shows want of coincidence between chemical and visual focus must at once be condemned.

The method of testing is as follows: A row of cards, or of other similar objects, is placed upright in a line so nearly behind each other as is compatible with seeing a number written on the top part of each to distinguish it from the others. There may be, say, seven cards, with a space of 6 inches between each two. The camera is placed at a distance of, say, 15 feet, and card No. 4, that is to say the central one, is carefully focused. A plate is placed in the dark slide, and a photograph is taken with full aperture of the lens under examination. If, in the photograph, card No. 4 appears the sharpest, the result is satisfactory. If, however, a card either in front or behind appears to be sharpest, the lens must be

condemned. It is assumed that the ground glass and the dark slide are in perfect register.

To Compare Lenses as Regards Flatness of Field, Marginal Definition, etc.—We shall suppose that two lenses of about equal focus have stood all the tests mentioned, and that it is desired to discover which of these is on the whole the best. Let us suppose them both to be portrait lenses.

The camera is placed opposite to some object consisting of well-defined vertical and horizontal lines. An old-fashioned window frame makes an excellent object. Modern plate glass window frames show too few lines.

If the lenses have different maximum angular apertures, that which has the largest aperture must be stopped down, so as to have the same as the other. The image is made sharp in the center of the plate, and the falling off of the definition towards the edges is observed, first one lens being used, then another. It will probably be found most convenient to take a photograph by each lens, and to compare the images. That lens which shows the least falling-off of definition at the edge is the best. Should the falling-off be about equal, but in one case be in the form of ordinary blurring, in the other in the form of astigmatism, the lens which shows merely blurring is to be preferred, as the fault can be corrected by the use of a small stop, which astigmatism scarcely can. If the lenses appear equal as regards falling-off of definition, that which has the largest maximum aperture is the best.

To Test for Distortion.—If it be suspected that a lens gives distortion, a weight should be hung with a fine cord, so as to get a straight vertical line; the camera should be placed opposite to this at some distance, with the length of the ground glass vertical, and should be turned till the image of the string falls quite on the edge of the plate. A straightedge is now applied to the ground glass to discover if the string is represented as a straight or as a curved line. If the latter, the lens distorts.

To Measure the Angle Included by a Lens.—The camera used for the purpose must be of such size that the lens cannot quite cover the ground glass. The smallest stop is inserted in

the lens, a bright distant subject having been focused, and the diameter of the circle which is illuminated is taken. As it is sometimes very difficult, with a very wide angle lens and a small stop, to see the image of those portions of a landscape which fell near the edge of the circle at all, it will probably be best to proceed as follows:

The sun is focused on the center of the plate at some time when it is pretty near the horizon. The smallest stop is inserted, and the camera is slowly swiveled till the image of the sun disappears. The spot where it was last seen on the ground glass is marked. The camera is now turned in the opposite direction, and the spot where the image of the sun was last seen is again marked. The distance between the two marks is the diameter of the circle covered. To tell what the angle is the following construction is made: A line, A B, is drawn = the focal length of the lens. At B a line, B D, is erected perpendicular to A B, this line if produced. B D and B C are each made = radius of the circle. A C and A D are joined. The angle, C A D, is then measured with a

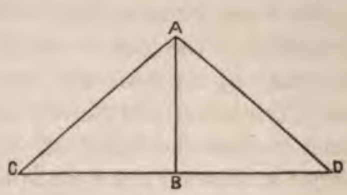


FIG. 34.

protractor or otherwise, and is the angle of the diagonal of the largest plate that can be used. To discover if the lens will cover any given size of plate, the circle is drawn out on paper, and it is found by actual experiment whether or not the plate will come within it. For example, the diameter of the circle is 16 inches. It is desired to find if a plate 12 x 10 will come within it, the plate is laid on the circle, and it is found that it just comes within it. Again, a plate 13 x 11 is tried, when it is found that it does not come within the circle, but that the corners project beyond it.

If it be wished to discover the angle subtended by the base line of the plate—the actual angle of view—the construction shown in Fig. 32 is repeated, but C D is made equal to the length of the plate in place of to the diameter of the circle. Thus, in the case imagined, it is made 12 inches in place of 16 inches long.

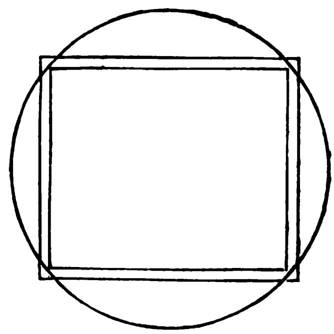


FIG. 35.

It is to be observed that lenses advertised as having an angle of view of fully 100 degrees and so forth never have anything of the kind. A lens to have such an angle of view would require to cover a plate of length about two and a-half times that of the focus of the lens. Thus a lens of 5 inchss equivalent focus would have to cover a plate 12 x 10. An angle of about 80 degrees is the largest ever included in practice, if we leave out of consideration certain obsolete forms of lens, such as Sutton's water lens.

To test the definition given near the margin of the circle illuminated by a very wide angle lens, it is necessary to make a negative of some well-defined subject, in a plane at right angle to the axis, and at some distance from the lens, using the largest plate that the lens will cover. The image on the ground glass is always too dull to judge by.

CHAPTER VII.

The Swing-Back Optically Considered.

There is probably no adjustment of the camera that affords to the beginner so endless a round of confusion as does the swing-back. In fact, not only is the beginner confused by it, but the experienced photographer very often does not thoroughly understand the action. So badly are the functions of the swing-back understood that it would probably be better for 99 per cent. of beginners and about 50 per cent. of experienced photographers—amateur and professional—to work with cameras having no such adjustment.

The cause of this confusion lies in the fact that the swing-back may be used for either of two purposes, which are quite different, and in some respects contrary one to the other. The confusion is not lessened by the fact that in most descriptions of the use of the swing-back one or other of its uses is entirely ignored, and that, when they are both considered, they are inextricably mixed up together. Farther than this, the use of the rising-front is closely allied to that of the swing-back, and adds to the confusion in considering the latter.

The "swing-back," all readers are presumably aware, is a term indicating an arrangement whereby the part of the camera carrying the ground glass can be rotated through a small angle, being swung either backwards or forwards so as to be no longer at right angles to the axis of the lens. This is the vertical swing; it has the result of placing the top of the ground glass farther from the lens than the bottom, or *vice versa*. The side swing is a similar arrangement for putting one side or end of the ground glass nearer the lens than the other.

The rising-front is simply an adjustment whereby the lens may be raised or depressed without tilting the camera.

There are some cameras which have what is called a swing-

front as well as a swing-back. This adjustment is very useful, but in reality it amounts in action merely to an extension of the rising-front principle. This will be explained a little farther on.

I shall now explain one of the actions of the swing-back. Let us suppose that we desire to photograph any object which is so high that, keeping our camera horizontal, and the lens in the normal position, the top part of the object is not included on the ground glass, while the upper part of the ground glass is filled with foreground which it is not wished to represent.

As a mere matter of including the whole of the object, we have two courses open to us. We can tip up the camera, or we can raise the lens. Fig. 36 shows the first action. If the

FIG. 36.

object have no straight lines in its composition—if it be a tree, for instance—the result may be satisfactory enough if the tipping is not excessive; but if the object be one in which there are vertical straight lines—if it be a house, for example—it will be found that these lines converge. This is due to the fact that the plane of the plate is no longer vertical, and the following rule must be taken as quite without exception: *If it be desired to render vertical lines in an object as parallel lines in a photograph, the plane of the sensitive surface must be kept vertical.*

We have now two courses open to us to secure this parallelism of the lines. We may swing the back till it is vertical, as shown in Fig. 37; or we may raise the front, as shown in Fig. 38. It will be seen that both courses result in a fulfilment of the conditions of the rule just given. It is worth while considering for a moment which it is best to adopt.

In all of the cuts, I have attempted to show approximately the amount of "straining" of the lens that will result from any adjustment of the camera. A dotted curved line shows approximately the field of sharpest focus. It will be understood that the farther this anywhere departs from the plane

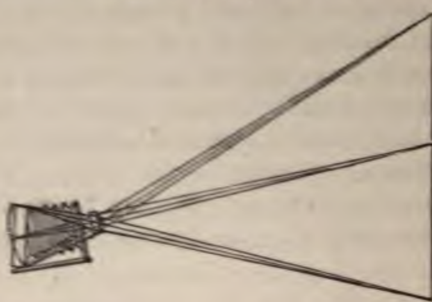


FIG. 37.

of the plate, the more will some parts of the subject be "out of focus," unless a very small stop to be used. It will be seen that the curved line departs from the plane of the plate much more in Fig. 37 than in Fig. 38, and in fact when the back is swung on in Fig. 37, it is often very difficult to

FIG. 38.

get all the subject in tolerable focus, using even a very small stop. We may, therefore, take it that where possible it is better to raise the lens than to tilt the camera and swing the back, and so it is although the arrangement does give rise to a slightly greater falling off of light toward the corner of

the plate representing the upper corners of the subject; but it will be seen that the raising of the lens involves the use of an instrument that will much more than cover the plate when conditions are normal. This results frequently in the use of the swing back simply because, if the front be much raised, the lens will not cover the lower corners of the plate at all.

Again, it often comes to pass that subjects are so high that even when the front of the camera is raised to the utmost extent, the top of what is wanted is still not included. In such a case it is necessary, besides raising the lens, to tip the camera and to swing the back.

If we look at Fig. 37, and suppose the camera fitted with an adjustment, so that the front can be swung forward till it is parallel with the back, it will be seen that the result would really be the same as in Fig. 38. This is why I said that the swing front came in practice to be merely an extension of the rising front principle. It is not the less useful on that account, however; it permits of a much greater rise than can be got without it.

We now come to the second use of the swing back, which, as we have said, is quite different from the first. In fact, it is as a rule only advisable where there are no vertical lines in the subject, and where therefore it is most necessary to keep the plane of the plate vertical.

Of course the photographer is aware that when he photographs a landscape, he photographs a number of objects at different distances from the camera, and that he cannot in nine cases out of ten get all these quite sharp at the same time except by the use of a stop more or less small. He can by adjusting the distance between the lens and the ground glass make any one or several of the objects sharp that he likes, and were it possible, at the same time, to have different parts of the ground glass more or less near the lens as might be desired, all the image might be sharp at the same time. Now this is possible in the case of a form of subject by no means very uncommon, namely one in which the lower part of the subject is nearer the camera than the center, the center than the top. The most complete case of such a subject

would be a flight of steps straight opposite the camera. Of course such a subject is seldom or never photographed, but it generally happens that the foreground is the nearest object in a landscape, that the center of the picture is considerably further away, and that the top is further away still—as perhaps, for example, the sky. Fig. 39 will show at once how by swinging the back so that the top is further from the lens than the bottom, the whole three parts are brought into focus at one time.

FIG. 39.

Another case in which the swing may be very useful is that of portraiture. In the case of a sitting figure, for example, the knees at the same time as the head may be brought into focus by the aid of the swing back.

The side swing is used when one *side* of the subject is much nearer the camera than the other. A typical example of such a case is that of a terrace of houses when it is desired to photograph these, looking along them from a spot nearly opposite the house at one end. The side swing is but little used compared with the vertical swing.

CHAPTER VIII.

Optical Principles Involved in Enlarging.

The optics of photographic enlarging will be very readily understood if what has already been written has been understood.

It has, of course, been observed by the photographer that, as he approaches an object to be photographed, he gets a larger image of it on the ground glass, and that he has at the same time to rack the lens out, or increase the distance between it and the ground glass. Now, if we have a camera which will extend sufficiently, this process need by no means stop at that point where the size of the image is equal to that of the object, but may continue till the image is very much larger than the object, the lens being always brought a little nearer the latter. In photographic enlarging the object consists of the negative from which the enlargement is to be made, and the image is received either on a sensitive surface, such as gelatino-bromide paper for the direct enlargement, or on a plate for the purpose of producing an enlarged positive, from which an enlarged negative may be made by contact. Some prefer to make a transparency by contact the size of the negative first, and to make this the object, producing an enlarged image in the camera. It is to be observed that when lenses that are not symmetrical—which consist of two combinations different from each other—are used for enlarging, as, for example, the portrait lens, it is well to reverse the objective when the image becomes larger than the object, turning that end of the lens which is normally toward the object, toward the sensitive film.

This is really the whole of the optics of enlargement; further complications—which are sometimes considerable—all have for their object merely the illuminating of the negative. It will of course be understood that the more light passes

through the negative into the lens the shorter need be the exposure. With modern films for enlarging, such as gelatino-bromide, it is unnecessary, in the case of daylight, to use any special means of concentrating the light. If behind the negative there be the sky or any evenly illuminated white object, as a board with a sheet of white paper stretched on it, the light will be sufficient. When, however, enlargements have to be made direct on, for example, such comparatively insensitive films as platinotype paper, albumenized paper, or carbon tissue, or in any case by artificial light—gas or oil—it is necessary to use an arrangement for concentrating the light. This is known as a condenser.

The condenser is nothing more nor less than a large lens or combination of lenses, one larger than the whole of the negative to be enlarged from. This lens condenses parallel or divergent rays, which pass through the negative and cause such as would otherwise fall outside the objective to pass into it.

We illustrate this here. A is, in this case, the source of

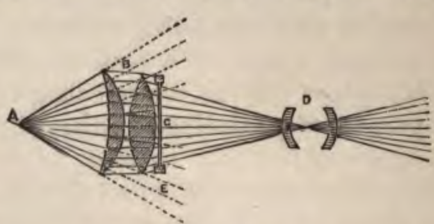


FIG. 40.

light; B is the condenser—a compound lens; C is the negative, held in a wooden frame E, and D is the objective or photographic lens. The relative distances of A, B, and D must be kept such, to get the best advantage of the condenser, that B brings the light to a focus within D.

In Fig. 41 is shown, to a smaller scale, the whole arrangement, including the screen on which the enlarged image is thrown, and the path of the rays of light. The form of condenser is an inferior, but much more commonly used one, than that shown in Fig. 40. The nearer to a point is the source of

light, A, the more easily can the whole of the light be thrown into the lens, D, even if be of smaller size; hence it results that with a light approaching a point in form, such as a lime light and a well-formed condenser, it is of no consequence as regards length of exposure whether the lens, D, be of small or

FIG. 41.

of large diameter, or slow-acting or quick-acting; and indeed, were it possible to have an absolute point as a source of light, and to have a condenser quite devoid of spherical and chromatic aberration, we might dispense with the objective D altogether.

When the sun forms the source of illumination, a condenser of longer focus may be used than with artificial light, as the rays are parallel to begin with, not divergent. It is necessary, of course, to have the sunlight always passing directly into the condenser. This is commonly provided for by having the enlarging camera so arranged that it may be turned in any direction.

From the *Photographic News* of December 23, 1870, we take an illustration showing the action of a solar camera.

Here B is the condenser, N is the negative, O is the objective or photographic lens adjustable by the pinion H, and R is the board for pinning the sensitive paper to, adjustable by the pinion *t*.

S is a vignetter which may be used if it be desired to produce vignettes. The shape is shown in the Fig. 36.

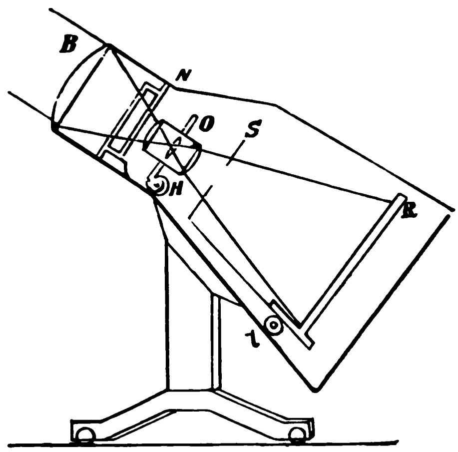


FIG. 42.

It is to be observed that when a condenser is used, especially with the sun as an illuminant, it is difficult to vignette with a simple oval opening, as in the case of direct enlarging, and that this difficulty is greater, the more optically perfect is the condenser. This is why it is *necessary* to serrate the edges of the vignettes.

Diagram 42 shows the external view of the solar camera with the sub-doors, which can be opened for inserting negative, sensitive paper, etc., and for observing progress when the image is visible, as in the case of albumenized paper.

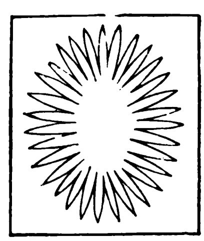


FIG. 43.

It has often been observed that whereas, when diffused light is used in enlarging, the quality of negative which is suitable

for contact printing gives excellent enlargements, that when a condenser is used, and especially when the sun is the source of light, such negatives generally give very hard pictures, and that, for such enlarging, the most suitable negative is one with very clear shadows and *very* thin high-lights.

These facts have often been observed, but I am not aware of having, as yet, seen any explanation of them. The cause of the harshness of result, when a condenser is used with a negative of ordinary quality, is as follows:

The shadows we shall suppose to be clear glass. This being "structureless" in the sense of showing no visible grain, the light passes straight through it, and, having been given that direction by the condenser, *all* passes into and through the objective. Of course we leave out of consideration, in the meantime, the small amount lost by reflection from the surfaces of the lenses and the glass of the negative, and absorption by the substance of these.

The high lights, however, are not structureless. The deposit forming them is not of the nature of a stain, but is more or less granular—consists, in fact, of palpable particles. Such a deposit, then, acts as a *diffuser* of light, causing a certain amount of it to spread in all directions. For this reason it is, of course, not all thrown into the objective. We have then this state of affairs: All the light passing through the shadows is thrown into the objective; only a portion of that passing through the high lights is so thrown, so that the amount of contrast between the two is increased.

It is of course true that, with diffused light to begin with, the high lights farther diffuse or scatter light reaching them; but, in this case, there being, so to speak, an infinite number of sources of illumination (every point of the first diffusing surface being a source of illumination), the loss of light at any point of the negative, by rays from one point of illumination diffused *away* from the objective by the film, is exactly made up by rays from other points of illumination diffused by the film *towards* and into the objective, so that the amount of contrast between high lights and shadows is, in this case, the same for enlarging as for contact printing.

CHAPTER IX.

VIEW-METERS AND FINDERS.

"VIEW-METER" is a term used to describe a small instrument which may be used to discover what amount of landscape will be included on the plates with any given lens. Its object is to discover, without the trouble of setting up the camera, which of a set of lenses must be used to include the subject settled on for the picture. The remarks on "Angle of View," Chapter VI, may with advantage be read in this connection. The simplest of all view-meters is a piece of string with some knots on it. It is held at arms-length in front of the operator, the distance between the hands being then determined by the position of two of the knots. There is then included between the hands the amount of landscape that the lens to which the knots apply will throw on the plate. Such a meter is very rough, but is wonderfully useful for those who carry a number of lenses; and it can very easily be made. A knot is made at one end of a piece of string. The longest focus lens is fixed on the camera. The amount of distant view included is observed. The knotted end of the string is taken in the left hand, and the string is drawn out at arms-length till there is included between the hands just the same amount of view as was on the plate, and a knot is made where the string is held by the right hand. The same is then done for each lens. Each knot then represents the angle included by one of the lenses.

Most view-meters are constructed on the principle of looking at the landscape through a rectangular opening of length and breadth proportioned to those of the plate. There is what is called an "eye-piece," which is simply a small hole to look through, toward the rectangular aperture, the only object of the so-called eye-piece being to insure that the eye is held at a certain fixed distance from the aperture. The distance between

the eye-piece and the aperture is generally variable to represent different lenses.

The annexed diagram shows a form of finder sold commercially, and will serve to make the principle of the instrument clear. B here is the aperture, and the square hole above A is the eye-piece. The distance between A and B is adjustable by sliding the aperture-piece along the plate, A C, and clamping it by the screw, B. The parts E F are merely for fixing the instrument to the camera when it is to be used as a finder, as will be described hereafter.

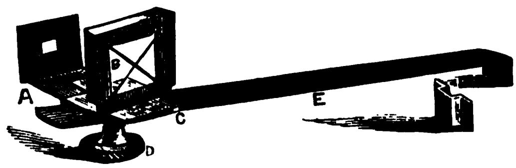


FIG. 45.

We will take an example to show the manner of adjusting this or any other view meter. Let us suppose that the camera is for 12 x 10, and that the opening of the view meter is 3 x 2 inches. This is not the precise shape of the 12 x 10 plate, but it is very nearly the shape to which we will probably trim the prints, and it is enough to remember that on the plate there will always be a little more subject both at top and bottom than can be seen through the meter.

We will suppose that the lenses in common use are of focal lengths, 20 inches, 16 inches, 14 inches, 12 inches, 10 inches, 8 inches, and 7 inches. We have now only to do a proportion sum as follows for each lens:

12 : 3 :: 20 : x the distance that we must have between the eye-piece and the aperture, so that there may be seen through the meter the same amount of view as the lens includes.

The distances will be, for the lenses mentioned, 5 inches, 4 inches, 3½ inches, 3 inches, 2½ inches, 2 inches, and 1¾ inches. These distances, however, to be quite correct, must be between the optical center of the lens of the eye and the plane of the aperture, and as it is not practicable to measure this, or to

know exactly how far the optical center of the eye-lens will be behind the eye-piece, the best thing to do in practice is to adjust the meter once for all by experiment for each lens as described for the crude string arrangement, and to mark the position of the aperture for each one.

It will be evident that the view-meter would be quite efficient with the distance between the "eye-piece" and the aperture fixed, if the latter size could be varied, and some view-meters are made on this principle. The fixed aperture shows the amount of view included by the widest angle lens, and there is a slit into which may be fixed smaller apertures cut in pasteboard or thin metal, just as in the case of a lens with Waterhouse diaphragms.

Finders.—The object of a finder is to be able to see what amount of subject is included by the lens whilst the dark slide is in the camera, and it is therefore impossible to look at the ground glass. They are particularly useful in the case of instantaneous work, particularly the taking of yachts, etc., as it is by means of them possible to follow the motion of the object, and insure that it occupies the proper place on the plate.

It will be evident that the meter just described might be used as a finder simply by fixing it to the camera with the plane of the aperture parallel with the plane of the plate, and so that no part of the camera obstructs the view of the subject through the "eye-piece" and the aperture; and, indeed, it often is so used.

I have used with success a very ingenious finder made by Mr. J. Adams. In principle it is somewhat the same as the above would be were the principle of fixed distance between eye-piece and aperture just explained adopted, and were a set of variable apertures used. Besides this, however, it has one or two points of novelty which make it specially worthy of notice. In the first place a mirror is used reflecting the light at right angles, so that the operator takes up a position at the side of the camera, where he may conveniently manipulate both the dark slide and the shutter. Besides this, there is a vertical and horizontal movement of the eye-piece con-

trived exactly in the same way as the same movements on the front of a camera. The use of these is to adjust the eye-piece, after the instrument has been fixed on the camera, so that precisely the same view may be included as that on the ground glass, even if rising or side sliding front be used.

The cut is a sectional plan of the instrument showing it about half size. It is made of vulcanite, is very small, and

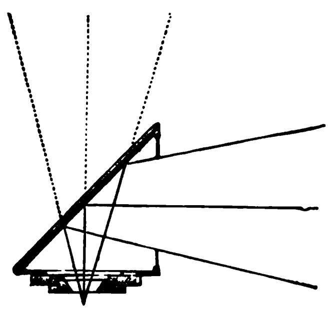


FIG. 46.

proved in our hands thoroughly practicable. It is not, so far as I know, made commercially.

A totally different form of finder is that which includes a small lens and a ground glass. It is, in fact, a miniature camera, and it will be evident that if such be used having the ratio of focal length to length of plate, the same as in the large camera, and if it be properly fixed on the large camera, there will always be on its ground glass the same amount of subject that the large lens includes. This is the form of finder generally used with detective cameras. In this latter case the lens of the finder is sometimes made of the same focal length as that of the main camera. In this case it is possible to focus by the aid of the finder—if both lenses are moved by the same rack—as well as to "find" the subject; but where, as is commonly the case, the lens of the finder is of much shorter focal length than that of the camera, there is no means of focusing after the dark slide is in the camera, and there is, therefore, no means of insuring sharpness in the image by focusing after the dark slide has been inserted,

unless we are using a very small stop, or the object is so distant that we may depend on its image being sharp when we focus for "the distance."

I know of two finders applicable to cameras which act as focusers. One is due to Mr. J. Traill Taylor. He purchases a cheap telescope whose objective is of the same focal length as that of the camera. The objective tube of the telescope is now fixed to the front of the camera, care being taken to keep the axis of the telescope and that of the photographic lens parallel. An object is focused on the ground glass, and the eye-piece of the telescope is drawn out till the same object appears quite sharp through it. The eye-piece is now fixed to the back of the camera so that the telescope slides in and out as the camera is racked in and out. The image in the camera will now always be sharp when the same object is in focus as seen through the telescope, and it is therefore possible to focus the former by looking through the latter.

The only objection that there is to this arrangement is that it does not act very well as a finder. It may be used to keep the camera directed to the object, but it does not show how much subject in included, or how large the image is on the ground glass, a very important matter when, for example, an instantaneous picture is being made of a yacht coming toward the camera. A device by Lionel Clark overcomes

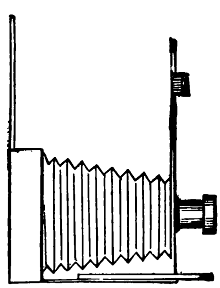


FIG. 47.

this objection. He uses a cheap lens of the same focal length as the camera lens—a spectacle lens which costs a few pence will do, he says—and adjusts that over the front of the

camera. The ground glass of the camera is arranged so that, if hinged upward, it will be held in a vertical plane, or more, strictly speaking, in a plane parallel with its normal position.

The illustration (Fig. 47) will show the arrangement.

The focusing cloth thrown over the upturned ground glass and the spectacle lens form a second camera. It is only necessary to focus some object sharply, with the ground glass in its normal position, to turn up the ground glass, and to adjust the lens, A, so that it gives a sharp image on the upturned ground glass, to fix the position of the lens, A, with relation to the camera front. The upturned ground glass will then at any time show the same amount of subject as is included by the principal lens, B, and if the camera be racked out till the image on the upturned ground glass is sharp, that on the sensitive plate will be sharp also.

CHAPTER X.

The Optics of Stereoscopic Photography.

Of late years the stereoscope has gone comparatively out of repute, and is but little heard of. We hear regrets on all sides that it has fallen in public estimation, but at the same time, those who are loudest in their regrets have done but little to set their old friend on his legs again. We hear almost all landscape photographers, especially amateurs, regretting the decline in public favor of the stereoscope, yet we never see them hoisting a stereoscopic camera and showing the results to their friends, a procedure which, if carried out by any large number of amateurs, would almost certainly raise the instrument, if not to its old proud position, at least to one of dignity.

Theories are often advanced as to why the stereoscope has fallen so completely out of fashion, but none of them seem to be very satisfactory. The probability is that it fell because it had, some twenty years or so ago, reached a height of popularity which its merits did not justify. There was, as was natural, a reaction, and it took too low a place. There are, however, signs now that the reaction may be over, and that the stereoscope may once more receive a fair share of popular favor. We shall hope so, for it is a very scientific and a very beautiful instrument.

The optical principles of stereoscopy are by no means complicated. They depend simply on the fact that, in the case of naturally looking at an object, the impression is really made up of two images, one received on each eye, *and each slightly differing from the other*, and that, if we can make two *pictures* of the object, differing just in the same way, and can arrange that each of them is seen by one eye only, we can reproduce faithfully the result of natural sight with two eyes, and will see objects *as if they were actually solid.*

If any one doubts that we see two different images with the two eyes, let him look at a landscape through a window, standing some eight or ten feet behind the latter. In this case, of course, the window frame forms part of the image. If now he look at the scene, first with one eye, then with the other, he will see that in one case he sees more of the landscape at one side; in the other case more of the landscape at the other side. Further, if there is, for example, a lamp-post in front of the middle of the window, he will find that it hides a slightly different part of the landscape according to which eye is used. We gain our idea of *solidity* of objects almost entirely on account of these two different images. We may, however, give an idea of *distance*, in the case of comparatively near objects, without seeing two different images, and this also on account of binocular vision. Thus, if a small, uniformly colored sphere be hung by a thread with a perfectly plane background behind it, we receive precisely the same image in each eye, yet we know that we can estimate with a fair amount of precision the distance of this sphere. This is because the axes of the eyes in all cases pass through the object looked at, necessitating less or more convergence, according as the object is far or near, and that a judgment of the amount of convergence, and hence of the distance, is automatically made from this datum.

We borrow an illustration from the "British Journal Almanac" of 1887 to illustrate this. In Fig. 48 objects A, B, and C are supposed to be at different distances from the eyes—shown as small circles—and it is seen how the axes converge more for the near than for the far objects.

It may not be granted at first that the appearance of solidity and the judgment of the distance of objects are due to binocular vision. It may be argued that if we close one eye we still see objects solid, and that we can still judge of distances to a certain extent. This is true, but is less true than at first appears. Familiar objects certainly appear quite solid, but that is greatly because we know so well that they are solid. If we view, for the first time, some object of complicated form with which we are quite unfamiliar, with one eye only,

we will often be sorely puzzled to make out its form. The judgment of distances by one eye only is more difficult than is imagined, as will be evident by the astonishment generally exhibited by the individual who is persuaded to let one eye

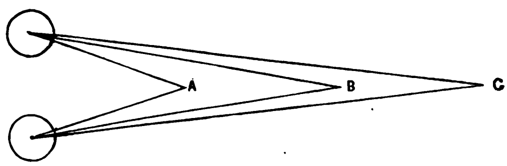


FIG. 48.

be bandaged up, and to attempt to snuff a candle immediately that it is brought into the room, when he repeatedly snaps the snuffers some inches in front of or beyond the candle.

The writer remembers the case of a lady who very frequently poured the milk or tea on to the tablecloth rather nearer her, or rather further from her than the cup into which it was intended to go. On an investigation it was found that, although she herself had not previously been conscious of it, the sight of one eye was so defective that she could scarcely be said to have binocular vision at all. But the most convincing experiment is that with the stereoscope itself. We take a common stereoscopic photograph and view it through a good stereoscope, when the moment the two images are combined, the picture appears to start at once into a solid object.

The Stereoscopic Camera.—The method of getting the two pictures, differing as do the images received on the two eyes, is simply to take two photographs from slightly different points of view. These points of view should, strictly speaking, be just as far apart as the two eyes, and very little more than that is permissible in the case of very near objects—portraits, for example—but for more distant objects there is no appreciable departure from truth by making the distance apart of the two points of view somewhat greater than that of the eye—say 4 or even 5 inches, for example—and the result is a more convenient size of plate, and several other conven-

iences. By greatly increasing the distance between the two points of view an idea of solidity and relief may be given to objects so far away that unaided vision really shows no relief. These effects can scarcely be called natural, but they are sometimes highly useful. Thus an idea of the shape and formation of distant and inaccessible mountain peaks and coast lines may sometimes be thus got which could be obtained in no other way.

When stereoscopic photography first came into fashion, it was customary to make two exposures on two separate plates with the same camera, the lateral position being slightly changed between the two exposures. This custom has now so completely gone out of use that a bare mention of it is sufficient. A "stereoscopic camera" is now always used. This is in reality two small cameras, each fitted with a lens, fixed side by side, and so arranged that the lenses may be uncovered at the same time, giving at the same time two exposures, one on each half of a plate. The size of plate adopted is anything from $6\frac{1}{2}$ x $4\frac{1}{4}$ to 8 x 5. The latter size is strongly recommended by J. Traill Taylor, whose authority on the subject cannot be disputed.

The Lenses.—Any kind of lenses suited to landscape work may be used with the stereoscopic camera, or for portrait work the portrait lens may be used. All that is said about angle of view, etc., in the chapters on lenses applies in the case of stereoscopic work; there is this difference, however, that the common form of stereoscope slightly *distorts* the image given with a rectilinear lens, while it *corrects* the distortion given by a single lens. The latter form is therefore peculiarly advantageous for stereoscopic work. The great thing, however, to secure is that the two lenses are of precisely the same focal length. Almost all opticians issue lenses "paired" for stereoscopic work, and these will generally be found to be of the same focal length; but they should be examined by accurately focusing a distant subject on the ground glass, and by measuring with a pair of dividers the distance between the same pair of points near the ends of the images given by the two lenses.

The Stereoscope.—The stereoscope is the instrument whereby it is contrived that each eye views only one of the two small pictures made of the subject, and that the two images are combined.

A little consideration will show that if we print our two views from the two negatives which are on the same piece of glass, or one piece of paper, and place the resulting print opposite to our eyes, the wrong picture will be opposite to each eye. The picture which should be opposite to the left eye will be opposite to the right, and *vice versa.* If, however, we cut the print in two and reverse the position of the two halves, we will have the right picture opposite each eye. If, now, we have the power of causing the axes of our eyes to change slightly—or in the case of very small stereo pictures merely to become parallel—while looking at the print held only about a foot away, we can look at one image exclusively with each eye, and will immediately see the object stereoscopically—as if it were solid. Some have this power, most can train themselves till they acquire it; but it is convenient to use an instrument whereby the strain always produced by giving a parallel or diverging direction to the axis of our eyes whilst they are focused on a near object is avoided. In the older forms of stereoscopes, reflecting mirrors were used. Fig. 49 will illustrate the action of them.

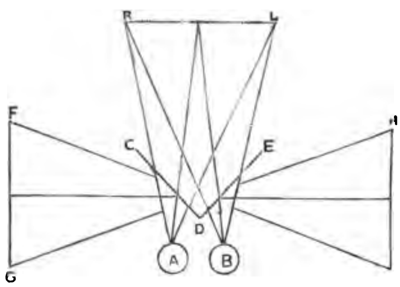


FIG. 49.

Here A B are supposed to be the eyes of the observer. The two photographs—slightly differing as already explained —are shown at F G, H I. The images of these are reflected by the mirrors C D, D E. These are arranged so that the angle between them can be slightly varied, and it will readily be under-

stood how it may be adjusted so as to make the two images overlap and form a stereograph at K L. I borrow Fig. 50 from a communication to the "Year Book" of 1886, by W. M. Ashman, which shows the reflecting stereoscope in perspective.

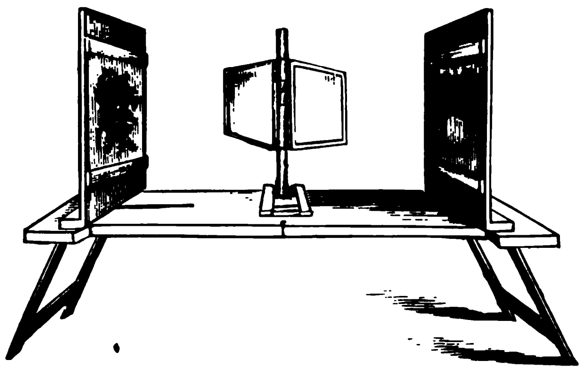


FIG. 50.

The reflecting stereoscope has certain advantages which have caused its revival to be strongly advocated quite recently, but its comparative cumbrousness is so much against it that it seems doubtful if it will ever come at all into general use again. The prismatic stereoscope has practically entirely ousted all other forms.

To explain elaborately this form of stereoscope would need

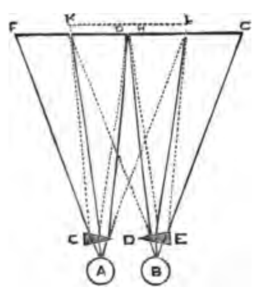


FIG. 51.

too much space, but it is briefly illustrated here. If the reader does not understand from Fig. 51 the manner in which the two prisms, C D, D E, cause the two images, F G, H I, to

combine and form a single image at K L, he is referred to Chapter III, where the prism is treated of. He will there find a description of the manner in which rays of light are caused to *bend* in passing through a prism.

The arrangement just shown is really all that is necessary to give a stereoscopic effect, but the effect is greatly heightened if these be combined with the prism's magnifier so that the image is slightly magnified. In practice this is secured by using as prisms the edge portions of circular lenses. Fig.

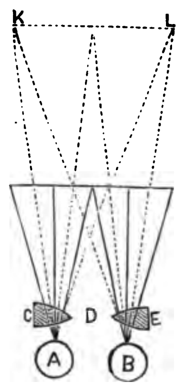


FIG. 53.

53 illustrates the arrangement. The letters refer to the same parts as in the case of the last drawing.

The next cut shows what portion of an ordinary double

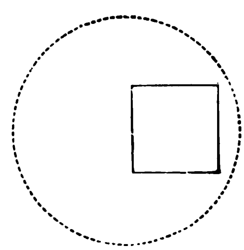


FIG. 54.

convex lens is used for the stereoscope prisms. The full lines show the part used, the dotted lines show the lens completed.

The reason why the use of a portion of a lens as the prism

of a stereoscope heightens the effect is, that it prevents the divergence of the rays entering the eye from any point of one of the pictures. Such divergence indicates to the eye the *nearness* of the object, as, for example, when we look at any object only a few inches off with only one eye. With the ordinary prisms we have this divergence, and although we get all the idea of solidity, the objects look merely like minute models. The lens causes the rays to become parallel, and if all adjustments have been correctly made the objects look, if not of their actual size, at least comparatively large.

Mounting Stereoscopic Prints.—Some special precautions have to be taken in the mounting of stereoscopic prints. In the first place, as has already been said, they must be reversed. A print is made from the two negatives on one plate, but of the two images that which is on the right as the print comes from the frame must be mounted on the left, and *vice versa.* Other points besides this need special attention.

All the precautions that have to be taken in the trimming of ordinary prints must of course be taken in the case of stereoscopic prints. I here refer to the necessity that the edge of the print be made parallel with vertical lines of buildings. It is necessary to give another precaution, which would appear unnecessary, but that a mistake is often made in this respect. The images must be trimmed to precisely the same *height;* that is to say, the trimming must be so done that any object is precisely the same height from the bottom of the picture in the case of one print as in the case of the other.

All this is simple enough, and will be readily understood; but the trimming of the edges is more difficult because the very conditions which are so strictly observed in the case of top and bottom must be avoided in the case of the sides. Any given point of the image must *not* be equally near the right or left side of the picture in the case of the two prints. The reason for this is that the stereoscopic image—appearing solid—must be seen with a distinct boundary line, and, to get an idea of size, it is necessary to arrange that this boundary line should appear as a framing *through* which the image is seen, whereas, if we trim the prints similarly at the edges

it will appear as if the whole image *stood out from* the framing.

We will see what is required if we look at a landscape through a window standing say some six or eight feet behind it. If we look at the landscape first with one eye, then with the other, we will see that whilst we are looking with the *right* eye, we see more of the left-hand side of the landscape, and less of the right-hand side, than when looking with the left eye. We must then trim our prints so as to produce the same effect; that is to say, we must let a little more of the image be seen on the *left* side, a little less on the *right* side in the case of the *right*-hand print than in that of the left hand. There is no rule as to the precise amount to be allowed, simply because there is no rule as to how near the "framing" of the picture should appear. It should, however, appear to be in front of the nearest part of the image, and to secure this it is necessary that in trimming the prints we should let a little more of the *foreground* be visible at the left side of the right-hand print, a little less at the right-hand side, than in the case of the left-hand print. In this case the conditions will hold to a still greater degree for all prints representing more distant objects than the foreground.

When a great number of prints have to be done from one negative, or pair of negatives rather, it is advisable to reverse the two halves of the plate and to print from them at once, after which the double print may be pasted directly on the mount. This is done in the following manner: The precise parts of the negative to be printed from are marked out, due care being taken in this case to allow a little more of the image on that edge of the negative which will give the left-hand edge of the right-hand print than on the corresponding edge of the other print, and a little less on what will give the right-hand edge of the right-hand print. The negatives are then cut with a diamond, allowing everywhere one-sixteenth of an inch outside the marked portion. They are then mounted in reversed positions—right for left—on a piece of clean glass by narrow strips of paper, all the same precautions as regards keeping them at the same height, etc., being taken as in the

case of prints. An opaque paper mask is cut, so as to shade all but the images that are to print. This new doublet negative is now used for direct printing, and the prints are mounted with no further precaution than has to be used in the case of mounting ordinary single prints.

CHAPTER XI.

THE SPECTROSCOPE.

THE fact that when a ray of white light passes through a prism it is divided up into various colors has already been mentioned. The row of colors obtained is called the *spectrum*. The study of the spectrum is a matter of great interest, and is one indirectly connected with photography.

In speaking, so far, of the passage of a beam of light through a prism, it has been assumed that that beam consisted of a single ray of light, or, in other words, had no breadth. This is, however, evidently an impossible state of affairs. The light must emanate from a source of light having some size. This source of light is commonly an opening of some kind having light—such as the sky—behind it; for example, a hole in the shutter of a darkened room.

If this opening be of a size larger than the smallest, the spectrum is continuous; that is to say, it is a row of colors without any break. If, however, the opening be made very narrow, be reduced to a fine slit, the spectrum from many sources of light—from the sun, for example—is found to be interrupted by a number of dark lines crossing it. In the case of certain sources of light these lines are bright in place of being dark. My object here is merely to describe the instrument called the spectroscope, and it is, therefore, impossible to go farther into the matter than to say that sources of light which consist of heated solids—for example, an incandescent electric lamp—give continuous spectra. Incandescent vapors—such as we have in the electric spark—give spectra consisting of bright lines; light which passes through the vapor of these bodies at a temperature below that of incandescence, is absorbed so as to produce dark bands, corresponding in position to those light bands which would emanate from those same vapors if in a state of incandescence.

The annexed cut shows the principal lines in the spectrum of the sun. I say the principal lines, because the real number is very great—many thousands—and the lines, before appar-

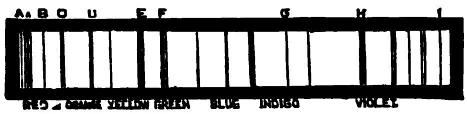


FIG. 55.

ently single, are almost daily found to be divisible. Any substance always gives, under the same circumstances, the same spectrum. It is, therefore, possible to judge of the composition of bodies, even when inaccessible, by the spectrum that they give. Thus, the spectra of many bodies well known on the earth have been observed in the light of the sun.

The spectroscope is merely an instrument for closely observing the spectrum. It consists essentially of a slit to admit light to one or more prisms through which the light passes. The light passes through a lens before it reaches the prism. This lens is called the collimating lens. Its object is commonly said to be to render the pencils of light passing from the slit *parallel.* This statement is scarcely correct, although continually made by those who ought to know better. It may really be looked upon as an objective, throwing an image of the slit on the screen for receiving the spectrum. The spectrum thus consists of an infinite number of images of the slit.

When it is desired to photograph the spectrum it is received on the sensitive plate, a photographic lens being, as a rule, interposed between the prism and the plate, although this is not an absolute necessity ; but when it is desired to examine it directly, a telescope, or it would perhaps be better to say a compound eye-piece, is used. The difference here is precisely the same as that between a camera and a telescope. When we wish to *photograph* an object, we receive the image given by the photographic objective on the sensitive film; when we wish to examine a distant object by the eye we look at the image given by the telescopic objective through an eye-piece.

In figures 56 and 57 is shown the external form of the spectroscope. In each case the left-hand tube supports the

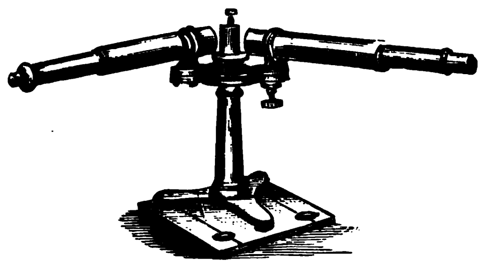


FIG. 56.

slit and the collimating lens, the right-hand tube the eye-piece for examining the spectrum. The second cut shows a spectroscope with two prisms. The advantage of two prisms in

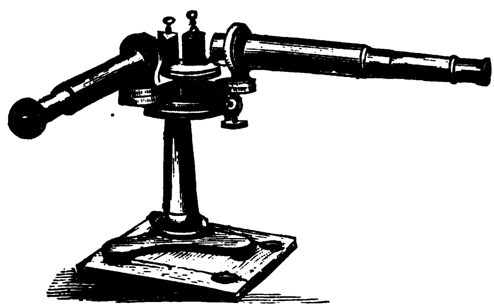


FIG. 57.

that greater dispersion is obtained; in fact, we get a spectrum on a larger scale than before.

Sometimes quite a number of prisms are used to gain greatly increased dispersion. An arrangement—the invention of the famous optician Browning—for the use of six prisms, is shown in Fig. 58; the dotted line shows the direction taken by a ray of monochromatic light. Mention must on no account be omitted of the direct vision spectroscope, as this is a little instrument particularly useful to photographers.

By referring to what has been said in Chapter III on the means of correcting chromatic aberration, and considering

how we may *bend* a ray of light without *dispersing* it, it will readily be understood that, by a modification of the same arrangement, we may *disperse* a ray of light without *bending*

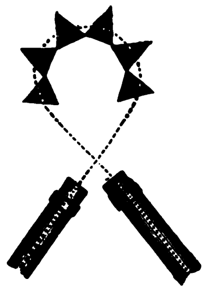


FIG. 58.

it. By so doing, we may have a spectroscope with the collimating tube and the eye-piece in a straight line, in place of at an angle with each other. Only a limited amount of dispersion is, of course, permissible with this arrangement, or the spectrum would pass beyond the field of view.

The next two cuts, Figs. 59 and 60, show the arrangement

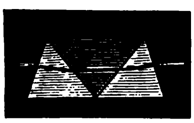


FIG. 59.

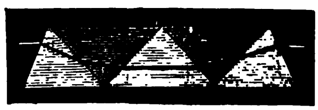


FIG. 60.

of prisms for dispersing a beam of light without deflecting it. In each case the darker shaded prisms are of flint, the lighter of crown glass.

The chief use of the direct vision spectroscope to photographers is in examination of mediums for dark-room illumination. Most photographic work is done by light of short wave lengths—blue, violet, etc. Sensitive films are, therefore, most easily worked in light of long wave lengths—red, yellow, etc. Colors that appear to the eye quite simple are often in reality compound. Thus, there are two kinds of red glass, to the eye as like each other as can be, but one of which transmits

only red light and, perhaps, a very little green, while the other transmits a considerable amount of blue or purple also. The latter, it will be evident, is quite unsuited to dark-room illumination. The two cannot, as has been said, be distinguished by the eye, but they can at once when the light passing through them is examined by the spectroscope.

The spectrum extends in both directions beyond what can be seen by the eye, the rays of greater and less refrangibility than those visible to the eye being termed ultra-violet and ultra-red rays. Photography has been particularly useful in mapping these.

There is the objection to the prism spectroscope that the glass of the prisms absorbs—or *stops*—some of the invisible rays. Fortunately a spectrum can be obtained otherwise than by a prism. It can be got by the aid of a "diffraction grating." A diffraction grating is a polished surface—such as speculum metal—ruled with lines so close together that there are many thousands to the inch. This, on account of what is called *interference of light*, gives a very perfect spectrum, none of which is absorbed. The subject of the diffraction grating is rather too complex to treat of in detail here.

CHAPTER XII.

On Instantaneous Shutters.

It may be thought that the instantaneous shutter is scarcely an optical instrument, but the use of it is so closely connected with the use of lenses that I incline to introduce a chapter on it.

An instantaneous shutter is merely an instrument for giving a very short exposure; for allowing light to act through the lens for a shorter time than it is practicable to allow, using the cap by hand. Its object is to photograph such objects as must not get a long exposure, on account of their being in motion.

At first sight it would appear as if nothing could be simpler than to construct an instrument fulfilling all the conditions required in an instantaneous shutter, but in reality the conditions are complicated, and they are not very easily fulfilled. In fact, it might almost be said, as it has been of lenses, that some of the qualities desirable are incompatible, and that we must at times sacrifice one or more of the less important to secure the others, the result being an instrument, not hypothetically perfect, but useful in practice.

In the first place, the photographer must disabuse his mind of the popular, or at least by no means uncommon, idea that an "instantaneous exposure" is something definite. The terms "absolutely instantaneous," "snap exposure," and so forth, tend to raise confusion. As a matter of fact, an instantaneous exposure occupies a space of time which, if short, is quite as definite as a long exposure. It is, moreover, as desirable to be able to vary the exposure when it is a case of $\frac{1}{20}$, $\frac{1}{10}$, or $\frac{1}{4}$ of a second, as when it is 4, 10, or 20 seconds. For by far the greatest quantity of instantaneous work an exposure not shorter than $\frac{1}{20}$ second is short enough, but there are special cases when it may be desirable to give shorter expos-

ures, say even as short as $\frac{1}{100}$ second. This is leaving out of the question a certain department of work for which extraordinarily short exposures are desirable. I refer to illustrations of "animals in rapid motion," such as have been so successfully produced by Muybridge, and for which exposures much shorter than $\frac{1}{100}$ second are necessary. This is a special work which needs a training in itself, and I do not pretend to be competent to give instructions in the matter. For such instantaneous photography, however, as is likely to come within the sphere of work of the ordinary photographer, professional or amateur, I consider that $\frac{1}{100}$ second is the shortest exposure that will ever be needed.

Another matter to be considered in connection with an instantaneous shutter is that it allows a good *coefficient* of light. This is a matter a little difficult to explain, and I may say that neglect of it is one of the commonest faults in instantaneous shutters. The object of giving a very short exposure is to avoid the blurring which would arise from the motion of the object to be photographed during a comparatively long exposure. The period of the exposure is from the time that the shutter *begins* to open until such time as it is completely closed. As, with instantaneous exposures, we, as a rule, have to use a larger diaphragm than we otherwise would, or else are liable to under-exposure, it is eminently desirable that, during the period of exposure, the light should be allowed to act with as much force as possible; that is to say, that the opening of the shutter should not be such as to allow the light to act with only *partial* force during the exposure. Now with a very common form of shutter, one in which an opening of the diameter of the lens crosses the aperture of the lens—a common form of drop shutter, for example—the lens is *fully* open for only an infinitely short space of time, and the total amount of light allowed to pass through the lens during the whole exposure is only one-half of what it would be were the lens fully uncovered from the beginning to the end. The effect is the same, as regards reductions of the light received by the plate, as if a stop of half the area were used, while there is none of the advantage, in the way of

greater "depth of focus" and better marginal definition, that would arise from the use of the smaller stop. Were we to use, in place of the shutter having the poor coefficient, one having the best coefficient possible, we could, with the same time of exposure—and therefore with only the same liability to blurring from motion of the object—either use a stop of half the area with possible great advantage, or, using the same stop, have a plate just twice as well exposed.

The manner in which a shutter effects the *distribution* of light on a plate is a matter needing consideration. It is, of course, known to all photographers that the illumination given by a lens on a plate is not equal—that it falls off from the center to the edge of the plate. This falling off is not very evident when only a small angle is included; but it is when we come to include an angle at all considerable. Moreover it is, even when only a moderate angle is included, considerable, when we use a lens of the rapid landscape form full aperture, or nearly full aperture; and this is the form most likely to be used in cases of instantaneous work. It is, of course, undesirable that a shutter should, by its action, increase this inequality of illumination; but there are some forms of shutter that do so. Before entering on this subject we should say that shutters which work at the lens may be divided into three classes—namely, those that work in front of the lens, those that work behind it, and those that work between the combinations; and that these may further be classified under the heads of such as consist of a single opening crossing the aperture of the lens; those that consist of two openings crossing each other, so that the opening for exposure begins and ends at the center of the lens; and those of the "go-and-return" nature, in which a flap is raised from in front of the lens and is again lowered, or in which one flap rises and another comes down very shortly afterwards.

Without entering into a detailed account of the action of these various forms of shutter in altering the distriution of light, I may give the following summary: Single opening shutters, whether behind or in front of the lens, do not modify the lighting as regards falling off from the center to any

marked degree; but, in the case of a vertical motion, give a somewhat longer exposure to the sky than to the foreground when in front of the lens; a somewhat longer exposure to the foreground than to the sky when behind the lens. The latter form of inequality is, of course, to be preferred to the other in the vast majority of cases.

In the case of a single opening working between the lenses, there is a slight additional falling off of light, produced at the top and bottom of the plate, or at the two ends if the opening be worked horizontally. The distribution of light as regards foreground and sky is not appreciably altered.

The case of two openings crossing each other is, perhaps, the most important to consider, as in this form of opening it is possible to get both the greatest disturbance of distribution of illumination and the greatest equality of illumination, according to where the shutter is placed. In most cases of shutters made with openings crossing each other the shape of these openings is made such that the actual exposing opening is of a square form; while the shutter is opening and closing, as shown in the accompanying sketch, and there are decided advantages in this form of opening.

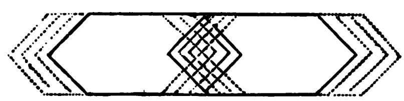


FIG. 61.

With the form of shutter under consideration, placed either in front of or behind the lens, the falling off of illumination at the margin of the plate is *very considerably increased*, so that it is never advisable to use such a shutter in either of these positions. On the other hand, if such a shutter be placed between the lenses, the result is a distribution of light even better than is got by using the lens with the same stop, and exposing by the aid of the cap.

There is an advantage in the opening beginning at the center of the lens which is quite peculiar to it. It is that the loss of light due to the time occupied in the opening and the closing of the lens is partly compensated for by the fact

that the opening acts as a stop *during that part of the exposure.* The result is that the picture shows the qualities it would were it taken with a *slightly* smaller diaphragm than that actually in the lens; but it is a great mistake to suppose that, when the shutter gives an opening in the center of the lens, there is no further necessity for stops at all.

That a shutter should not have the effect of shaking the camera during the exposures is of course essential, and it is far more difficult to secure the complete absence from shaking than might be supposed, especially when a rapid exposure is needed.

I believe that there is only one way of securing absolute immunity in the case of very short exposures from any impulse conveyed to the camera, and that is by having two moving parts of equal weight moving at equal rates of speed in opposite directions at the same time. I leave out of consideration the arrangement which may be made in some very special cases where the shutter is supported on a stand separated from the camera. The two moving parts may be made in the form of rectilinear or similarly shaped shutters moving in straight lines, or of two circular dishes centered on the same pivot and revolving in opposite directions at the same time.

In the case of a drop shutter actuated by gravity only there is but little tendency to shake till the exposure is over; but with every form of shutter in which one moving part is actuated by a spring or analogous contrivance fixed to the shutter, an impulse is given to the camera during exposure tending to shake it, and if the results are not practically detrimental, it is merely because the shaking produced is so slight as not to be appreciable. This is only to be secured by making the moving part very light.

Of "go-and-return" shutters pretty much the same thing may be said. It is not possible to so construct them that they do not communicate an impulse to the camera at the time of reversal of the motion, or, where two flaps are used, at the moment when the motion of the first one is stopped. It must, however, be admitted that the weight of the moving

parts in certain modern "go-and-return" shutters has been so much reduced that the impulse produces no appreciable effect, while the compactness possible in shutters of this form is much in their favor. Further than this, it is possible, when a "go-and-return" motion is combined with a revolving motion, to compensate the impulse given by the reciprocating part by unequally weighting the revolving part. This has been done in the case of a very ingenious shutter mentioned by J. R. Gotz.

The principal conditions to be satisfied in the case of a perfect shutter may be said to be the following:

It must be capable of giving a short exposure.

It must be capable of giving a variable exposure.

It must be a good coefficient of light.

It must not increase the inequality of distribution of light given by a lens.

It must not shake the camera.

Of course there are other conditions, such as lightness, portability, and simplicity, but these are self-evident.

A few words on the above-mentioned conditions. I have already stated what I consider to be the shortest exposure that it is ever necessary to give in ordinary practice,

As regards variability, it should be so great, if possible, that anything, from the shortest exposure ever needed, to one of $\frac{1}{5}$ second, or even longer, can be given. It is possible to give, with a little practice, exposures of $\frac{1}{4}$ second and upwards by hand; still it is very great convenience to have a shutter with which exposures of several seconds can be given if it be desired.

As to a good coefficient of light, I know of only one way of securing this in the case of shutters consisting of one or more openings crossing the axis of the lens. It is to have the openings long in the direction in which they move, and to compensate for this length by an increased rapidity of movement. To secure even a *fair* coefficient of light the opening or openings should always be at least two or three times as long as the actual working diameter of the lens, and this particularly in the case of a shutter opening in the center by two apertures crossing each other. In this form of shutter, if the openings

be square and the diagonal of the square equal to the diameter of the lens, the coefficient of light is only $\frac{1}{8}$; that is to say, the lens is only permitted to act with $\frac{1}{8}$ the intensity actually due to its angular aperture, and the plate receives only $\frac{1}{8}$ the amount of light that it would with a hypothetical shutter.

A few words will be said farther on as to the best actual form of aperture which secures the best coefficient of light—considerable *length* of aperture being pre-supposed—in the case of a single moving part.

I have already stated that it is more difficult to secure immunity from the shaking of the camera by the lens during the exposure than might be imagined.

In the light of what has just been said, we shall briefly considered several of the most efficient shutters commonly used.

I must, first of all, however, say that I have spoken of shutters only as placed before or immediately behind the lens, or between the combinations, because the vast majority of shutters work in one or other of these positions. There is, however, one shutter which works, not near the lens at all, but close to the plate. This is the curtain shutter of Mr. B. J. Edwards, and it has certain advantages over any other form of shutter. It consists of a curtain of a flexible opaque material, which is made to move rapidly across the plate by being rolled off a roller at the top of the camera on to one at the bottom. Those who know the structure of any "roll-holder" or roller slide, or who consider how a panorama is worked, will readily understand what is meant. There is a slit in this curtain transverse to the direction of its motion. This slit of course lets light pass. There is an arrangement whereby its width can be varied so as to admit of varying exposures.

It may be said of this shutter that it satisfies *all* the conditions laid down, while it has one property peculiar to itself: it gives a better coefficient of light than any other shutter. In fact, it gives the hypothetical coefficient.

On the other hand, the shutter is of necessity bulky—although it may be arranged so as not to add much to the size or weight of an already bulky camera—and it has a defect peculiar to itself. Although the exposure of any one part of

... an appreciable lapse of ... and the bottom of the ... The result is that one ... later than another. ... express train, occupying a ... part of the width of ... photographed, the train ... advanced some five or six ... between the times when the lower ... driving wheels and the ... the funnel were exposed. The ... would perhaps be curious. It ... that this objection is rather a ... theoretical one than one likely to ... to trouble in practice.

... Drop Shutter must have a word ... of notice, because, although it ... imperfect in various respects, its ... extreme simplicity makes it very use... for a great deal of everyday instan... ...eous work. Its drawbacks are, that ... not give a very short exposure ... the aperture be so formed that ... a very bad coefficient of light. ... be arranged so as to give a ... coefficient of light, it gives an ... not very short, and is some... ...rous.

... advisable to use it at all for ... exposures. I illustrate here ... which has long been used by ... which will probably be ... as many others where ... never shorter than $\frac{1}{20}$ ... admissible.

... slits in the frame-work ... removed entirely for ... weight being supported

on a card or needle inserted in one or other of the slits, according to the length of exposure needed. With a shutler made as shown, and proportioned for a lens of $1\frac{1}{2}$ inch aperture, the exposure from the lowest slit will be about $\frac{1}{8}$ second, from the top one about $\frac{1}{16}$, from the intermediate one something *about* half way between these two.

The annexed cut shows the form of opening—due to Professor Pickering—which gives the best coefficient of light with a drop shutter.

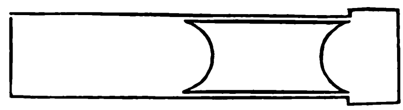


FIG. 63.

The next shutter I would mention is Wollaston's diaphragmatic. It consists of two disks revolving in opposite directions, between the combinations of the lens, on the same center. The apertures are long in the direction of motion, and the opening is in the center of the lens. The shutter fulfills all the conditions laid down, and has the advantage over most shutters, working between the combinations of the lens, that the continuity of the lens tube is not broken, so that there is no liability to disturbance of the "centering" of the lenses, a thing liable to occur, from the warping of the wood, in those forms of shutters where the combinations are screwed on to opposite sides of a wooden casing or framework. Moreover, the shutter provides for the use of diaphragms while it is being used as a shutter. The exposure may be varied from $\frac{1}{100}$ second to several minutes. The only drawback that attaches to the diaphragmatic shutter is, that it is somewhat heavy and bulky. This defect has been, in a great measure, remedied in recently constructed instruments.

Another form of shutter is constructed on the principle first laid down by Noton, who, so far as we know, was the first to suggest two parts moving in opposite directions at the same time, and securing an opening on the axis of the lens.

In point of construction and detail the shutter made by Messrs. Sands and Hunter is a great improvement on the

Noton. It fulfills all the conditions laid down, except that of giving a good coefficient of light, and this could easily be secured by a slight modification of construction, which, however, would probably make it impossible to get quite such short exposures as can be made with this shutter in its present form. This shutter is a great favorite with many, and excellent work has been done with it.

Mention has already been made of a shutter by Gotz, which is of the "go-and-return" pattern, but in which the impulse otherwise given to the camera at the time of reversal of the motion is compensated. A circular disk is moved up and down by a link actuated by a pin near the circumference of a revolving disk. By weighting the revolving disks at one side, an impulse is given which compensates that given by the reciprocating disk. The writer has used a shutter of this pattern of large size, and has found it very convenient.

FINIS

Having just concluded an arrangement with JAMES SWIFT & CO., of London, for the exclusive sale of their unrivaled photographic objectives in the United States, we take pleasure in announcing that we shall soon have all their various lines of Lenses in stock, and that a forthcoming catalogue is now in preparation and will soon be ready for distribution.

THE SCOVILL & ADAMS CO.

WATERBURY LENSES.

The unprecedented success which has everywhere resulted from the employment of the Waterbury Lenses, for 4x5 and 5x8 plates respectively, induced the Scovill Mfg. Co. to extend the series of this favorite objective. The popular C Waterbury Lens gave an opportunity for producing 8x10 and even 10x12 photographs with the sharpness, detail and brilliancy of the smaller sizes, but after its advent there was still a gap between the 5x8 and 8x10 sizes. The desire to see the Waterbury series complete had led to the production of the BB Waterbury Lens, which covers 6½x8½ (the ever-popular 4-4 size) to the extreme edges. In future, revolving diaphragms will be supplied with all of the Waterbury Lenses. In them are cut (with mathematical accuracy) openings in value $\frac{f}{15}$, $\frac{f}{20}$, $\frac{f}{25}$, $\frac{f}{35}$, $\frac{f}{50}$, respectively.

The Waterbury Lenses are composed of a biconvex crown glass lens cemented to another lens of the plano-convex form, made of the best selected flint glass.

Owing to the great advances in the sensitiveness of emulsion plates, the Waterbury Lenses are now commonly used for groups and for instantaneous views, with the Scovill Safety Shutters, described on another page. No better testimony can be given to the excellence and reliability of these objectives, and the mathematical accuracy with which they are made, than that deduced from the recent test made of 392 lenses of the C series, in which large number only two lenses differed at all in focal length of luminous power from the others.

	Diameter. Inches.	Back-focus. Inches.	
A, Single, for 4 x 5 plate	$1\frac{6}{16}$	6	$3 50
A, Matched pair, stereoscopic			7 00
B, Single, for 5 x 8 plate	$1\frac{11}{16}$	10	4 50
B, Single, for 5x8 plate, with patent instantaneous Shutter			5 50
BB, Single, for 6½ x 8½ plate	$1\frac{14}{16}$	10¾	6 00
C, Single, for 8 x 10 plate	2½	16	8 00

The Scovill Economic Lenses.

These Lenses are intended to fill the want experienced by thousands of successful workers with the Waterbury Lens for a good, low-priced Recti-linear Wide-Angle Lens, whereby they can gain artistic effects in perspective at short distances.

PRICE SCOVILL ECONOMIC LENSES.

No.	Size of Plate.	Back Focus.	Equivalent Focus.	Price.
2	5 x 8	5 inches.	5½ inches.	$12 00
3	6½ x 8½	6 "	6½ "	15 00
4	8 x 10	8 "	8½ "	20 00

Morrison Wide-angle View Lenses.

These Lenses are absolutely rectilinear; they embrace an angle of fully 100 degrees, and are the most rapid, and are universally conceded to be the best *wide-angle* lenses made.

No.	Diameter of Lens.	Size of Plate.	Equivalent Focus.	Price.	
0	1 inch	3¼ x 4¼ inch	2¼ inch, each,	$20 00	
3	1 "	4¼ x 6½ "	4¼ " "	25 00	
4	1 '	5 x 8 "	5¼ " "	25 00	These 3 sizes will fit into 1 flange.
5	1 "	6½ x 8½ "	6½ " "	25 00	
6	1 "	8 x 10 "	8 " "	30 00	
7	1¼ "	11 x 14 "	10½ " "	40 00	These 2 sizes will fit into 1 flange.
8	1¼ "	14 x 17 "	14 " "	50 00	
9	1½ "	17 x 20 "	17 " "	60 00	These 3 sizes will fit into 1 flange.
10	1½ "	20 x 24 "	22 " "	80 00	
11	1½ "	25 x 30 "	28 " "	100 00	

☞ Nos. 1 to 6 are all made in matched pairs for stereoscopic work. The shorter focused Lenses are especially adapted for street and other views in confined situations. For general purposes, a pair of No. 5 Lenses will be found most useful.

We desire to call your attention to the

Morrison Combination Wide-Angle Lenses.

The acknowledged superiority of the Morrison Wide-angle Lenses, and the desire of photographers to have a number representing the various focal lengths in as compact form as possible, rendered it necessary for Mr. Morrison to devise a scheme for combining the various foci in one instrument. This he did a year or two since, and his "Combination" Lenses are now in great demand.

An elegant morocco case, velvet lined, four and a quarter inches long by two and a half wide by one and three-quarter high, contains one eight-inch Wide-angle Lens in its usual brass mounting, with revolving diaphragm, and a set of Lens Cells of four, five, six, and eight inches focal length respectively. These Lens Cells are interchangeable, and the operator is thus possessed of one Lens Combination by which he secures focal length of four, five, six, seven and eight inches, and hence is fully equipped for interior and exterior work from 4x5 to 8x10 in the most confined situations, or for landscapes at nearest and greatest distances from the point of observation.

The device is so simple that it will be readily understood from the following explanation. Put in Cells as follows:

Front.		Back.	
5	with	4	for 4-inch Back Focus.
5	"	5	" 5 " "
6	"	5	" 6 " "
6	"	8	" 7 " "
8	"	8	" 8 " "

Thus the operator combines five focal lengths in one Lens.

These Lenses if purchased separately, would cost in the aggregate $180, thus a saving of $55 is effected.

No. 1, price complete in morocco case..................$75 00
No. 2, combining four, five, and six inches focal lengths... 55 00

THE
INSTANTANÉ LENS.

With Aluminum Mount and Iris Diaphragm.

The several lenses which form the combination of the Instantané are ground from the newly invented glass which has found such prompt recognition in Europe. By reason of the crystaline purity and whiteness of this glass, the Instantané will be found to answer the most difficult requirements in *Speed*, and to work satisfactorily when others fail.

Having such a remarkably brilliant, yet soft illumination, this lens will be found vastly superior to all others of the Rectilinear class for Portraits. Used with the full opening, it takes a portrait of very superior quality.

The Instantané Lens is perfectly Rectilinear, and entirely free from astigmatism, even when used with its full aperture. It has the most remarkable depth of focus ever produced in any lens of the character.

The Instantané is one of the few lenses that are really Aplanatic. It is guaranteed not only to cover the size plate for which it is sold, but to do this without the least loss of definition on the edge of the plate.

It has a good field, although not so forced a capacity as some, resulting in a considerably larger image of the principal object than any other lens of its size would yield, besides absolute freedom from any distortion whatever.

Price List of Instantané Lenses.

		Equiv. Focus.	
No. 1, for 4 x 5	size, instantaneous or timed photographs....	6 inches..........	$30 00
No. 2, for 5 x 8	size......................	8 "	35 00
No. 3, " 6½x 8½	"	10 "	50 00
No. 4, " 8 x10	"	12 "	60 00

4x5 Instantané Lens, with Inst. Shutter and Iris Diaphragm, price $40.00.

SCOVILL'S PORTRAIT LENS,

For 3¼x4¼ and 4x5 Portraits, or in pairs for Stereoscopic Views on 5x8 plate....................................price each, $8 75

Scovill's "Peerless" Quick-Acting Stereoscopic Lenses,

FOR PORTRAITURE OR VIEWS.

These Lenses are especially designed for Stereoscopic Photography, and are so constructed that they will work well for interiors or exteriors.

They are particularly adapted for instantaneous work.

Diameter of Lenses, 1½ inch ; focal length, 8½ inches.

By removing the back lens and substituting the front combination a focal length of 5½ inches is obtained.

They are supplied with six Waterhouse diaphragms in morocco case.

Price, per pair............... ....$25 00
Imitation Dallmeyer Lens.......................... .. ...each, 9 50
" " Lenses, matched for Stereoscopic Work, per pair, 17 00

Darlot Wide-Angle Rectilinear View Lenses.

These Lenses embrace an angle of 90 deg., and are valuable for taking views of buildings, interiors, etc., in confined situations, where those of longer focus cannot be used.

	Back Focus.	Size View.	Price.
No. 1,	2½ inches......	For Stereoscopic Work, each............	$12 50
" 2,	3 "	" " "	15 00
" 3,	5 "	" " "	20 00
" 4,	8 "	" " "	25 00
" 5,	12 "	" " "	35 00

Darlot Rapid Hemispherical View Lenses.

These Lenses embrace an angle of from 60 to 75 degs.; are quick-acting, perfectly rectilinear, and provided with central stops. Will be found very fine lenses for landscapes and outdoor groups ; also for copying engravings, maps, architectural subjects, etc.

	Back Focus.	Size View.	Price.
No. 1,	5½ inches...............	5x 6.	$15 00
" 2,	9 "	5x 8..........................	25 00
" 3,	10½ "	8x10...........	35 00
" 4,	14 "	10x14.	50 00

No. 1 can be had in matched pairs for Stereoscopic Work.

DESCRIPTION AND PRICES

OF THE

GUNDLACH RAPID RECTIGRAPHIC.

No.	Size of Plate.	Diam. of Lenses.	Equivalent Focus.	Focus of Back Lens.	Focus of Front Lens.	Price.
0	3¼x 4¼	13/16 in.	5 in.	8 in.	11 in.	$14 00
1	4 x 5	1 "	6¼ "	10 "	13½ "	20 00
1½	4¼x 6½	1⅛ "	7 "	11 "	14¾ "	25 00
2	5 x 8	1¼ "	8½ "	13½ "	18 "	30 00
3	6½x 8½	1½ "	11 "	17 "	23 "	38 00
4	8 x10	1¾ "	13 "	20½ "	28 "	50 00
5	10 x12	2 "	16 "	25¼ "	34 "	64 00
6	11 x14	2¼ "	18½ "	29¼ "	39½ "	76 00
7	14 x17	2¾ "	22 "	34¾ "	47 "	100 00
8	17 x20	3¼ "	26 "	41 "	56 "	125 00

The brilliancy of the image and especially the flatness of field and fine definition at the extreme margin of the plate place these new lenses decidedly ahead of any others.

The two triplets constituting the new lenses are of *different focal length*, the back lens having a much shorter focus than the front lens, and their relative curvatures are so calculated as to secure perfect *optical* (not geometrical) symmetry of the compound, and at the same time, to form perfect achromatic and aplanatic objectives, for themselves, if used singly. This novel plan offers the important advantage that these new lenses now in fact contain or consist of *three* objectives of different powers or focal lengths, which are of the following approximate proportion:

Equivalent of Compound 2,
Back lens alone 3,
Front lens alone 4,

thus giving, on the same plate, pictures differing in size about as 2 to 3 to 4. To use the back lens alone the front lens is to be removed and the hood screwed into its place. To use the front lens alone, the back lens is to be removed and the front lens screwed into its place. The focal lengths of the compound and of each separate lens are engraved on the mounts of the lenses.

STEINHEIL LENSES.

QUALITY, not quantity, governs in determining the price of lenses. By an examination of the following price list, which supersedes all previous ones, it will be seen that Steinheil lenses are sold lower than any first-class lenses with which alone they may be compared. The introduction of Steinheil lenses marked an important advance in photographic optics.

HOW TO SELECT A STEINHEIL LENS.

In order to meet the various requirements, and to insure in each special case as perfect work as possible, we make lenses of different constructions.

Our lenses are divided into six *series*, presented in the order of their respective rapidities. Each series begins with No. 1 for the smallest size, and continues upwards. To avoid errors, it is therefore necessary in ordering to quote both the number of the series and the number of the lens in the present catalogue.

All our lenses are rectilinear and are strictly corrected for spherical errors and chemical focus.

They are free from disturbing reflections, and strongly illuminated objects can be taken with them without producing flare or light spots. They are, moreover, constructed so as to give the greatest possible equality of definition over the whole picture.

In focusing with these lenses always use largest stop and focus on object of chief interest. Then without changing focus insert proper diaphragm to secure depth in foreground and background.

The scientific basis of our establishment and the precise methods employed both in the manufacture of our astronomical and photographic apparatus, enable us to produce lenses of such uniform acccuracy, that the means of most vigorous testing at our command fail to reveal any differences in the instruments we send out.

We make it a special point never to supply a lens which is capable of improvement at our hands.

According to the principle involved in their construction, our lenses are divided into two classes, viz: *Antiplanetic* and *Aplanatic*.

Antiplanetic Lenses.

(Patented in United States and Europe.)

Briefly stated, these lenses which are the result of a series of calculations extending through several years, are composed of two non-symmetrical combinations each of as great but opposite faults as possible, which

correct each other. One combination has a shorter focus than the objective as a whole, and the other has a negative focus. The combinations are placed closely together.

By the peculiar construction, as described above, differing widely from the usual forms, it has been possible to correct to a considerable extent the hitherto greatest defect in photographic objectives, viz., "Astigmatism," and the consequent rapid decrease of definition from the center to the margin of the picture.

The result is greater sharpness and depth distributed more equally over a larger and strictly even picture, before any decrease in definition is perceptible.

Illumination, too, is more evenly distributed in consequence of lenses being proportionately nearer together.

These properties allow the lenses to be worked with full aperture or large stops, and gives them great rapidity of action.

The perfectly correct delineation produced by the antiplanets render them particularly suitable for enlargements as well as for dissolving view apparatus.

If small and sharp originals are taken, and subsequently enlarged, depths are obtained which would be unattainable in larger pictures taken *direct* with same amount of light. For this purpose, which will probably play an important part in photography, the antiplanets are specially suitable.

In making enlargements the front lens of the antiplanets should always be turned towards the enlarged picture, and the back lens towards the object to be enlarged.

This construction is designed for strictly even and correctly delineated pictures, and all tilting of the camera should be decidedly avoided and a movable lens board used instead.

The antiplanets are made in two series: The portrait antiplanets (Series I.) and the group antiplanets (Series II.), the latter being, however, also excellent dry plate portrait lenses.

Aplanatic Lenses.

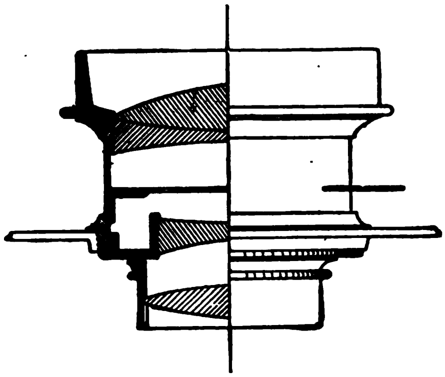
These lenses consist of the original and now well-known symmetrical and rectilinear combinations, invented by Steinheil in 1868 but not patented. They are made in four series, each of which is especially designed for a certain class of work. Their capabilities and object are fully explained below.

The lenses of Series V., also Series III., No. 1; Series IV., Nos. 1 and 2 have rotary diaphragms.

All the other lenses are furnished with Waterhouse diaphragms in morocco case.

STEINHEIL LENSES.

Series I.—Patent Antiplanetic Portrait Lens.



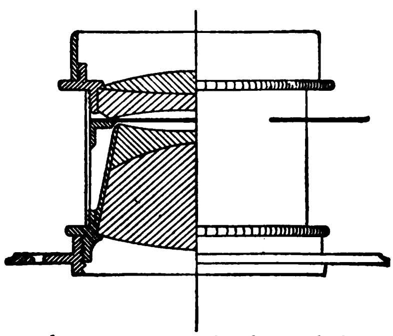
The rapidity is the same as in the usual Portrait Objectives, but there is more equality in the distribution of sharpness and illumination over the picture and greater depth. Contrary to the ordinary Portrait Objectives they produce perfectly correct delineation. Designed for *Portraits*, *Enlargements*, and *Dissolving View Apparatus*.

Series I.—Patent Antiplanetic Portrait Lens.

No.	Aperture, Inches.	Focal Length, Inches.	Plate, Inches.	Price.
1..............	5/8	2	Locket-Size.	$25 00
1*a*..............	1 9/16	4 11/16	1–9 plate.	50 00
1*b*..............	2 5/16	7 1/16	1–6 plate	75 00
2..............	3	9½	Carte de Viste.	100 00
3..............	3⅝	12⅝	Cabinet.	165 00
4..............	5¼	23⅝	Boudoir up to ½ life-size.	330 00

Special quotations for larger sizes.

Series II.—Patent Antiplanetic Group Lens.



New in principle and construction, consisting of two non-symmetrical cemented pairs, placed closely together. It is rectilinear, and is remarkable for its powerful and even illumination and sharpness. In rapidity, it is only excelled by the regular and expensive portrait combinations.

Recent improvements in the mounting of the lenses of this Series make them still more compact than formerly and allow the front hood of lens to screw off uncovering a screw thread which can be very conveniently used for adjusting lens to detective cameras, shutters, prisms or other appliances.

Designed for *Portraits*, *Groups*, *Architecture*, *Landscape*, *Instantaneous Work* and *Enlargements*.

Unexcelled for *Flashlight Portraits and Groups*.

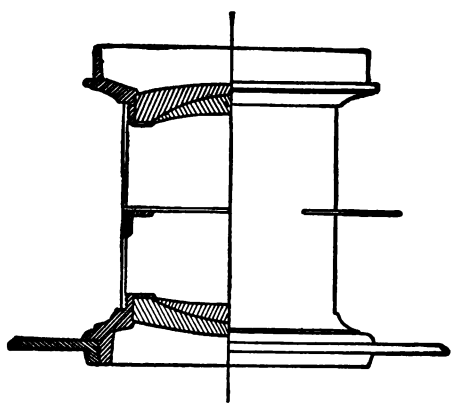
No.	Aperture, Inches.	Focal Length, Inches.	Size of Portrait or Group, Inches.	Size of View or Landscape, Inches.	Price.
0.......	3/8	1 7/8	1 5/8 x 1 5/8	2 x 2	$18 00
1.......	11-16	3 3/4	3 1/4 x 3 1/4	4 1/4 x 3 1/4	21 00
*1*b*......	13-16	4 7/8	4 1/4 x 3 1/4	4 1/2 x 3 3/4	25 00
2.......	1	5 5/8	4 1/2 x 3 3/4	5 x 4	28 00
*2*b*......	1 3-16	6 1/2	5 x 4	5 1/2 x 4 3/4	33 00
3.......	1 5-16	7 1/4	5 1/2 x 4 1/4	7 x 5	37 00
4.......	1 11-16	9 1/2	7 x 5	8 1/2 x 6 1/2	48 00
5.......	1 7/8	10 7/8	8 1/2 x 6 1/2	10 x 8	60 00
6.......	2 1/2	14 1/2	10 x 8	12 x10	95 00
7.......	3 1-16	17 3/4	12 x10	15 x12	140 00

* Special Detective Camera Lenses : No. 1 *b* for plates, 4 1/4x3 1/4 ; No. 2 *b* for plates, 5x4.

Nos. 0 to 3 are made in matched pairs for STEREO WORK.

Shutters of any desired make will be fitted to our lenses at manufacturer's prices.

Series III.—Improved Aplanatic Lens.



The prototype of all rapid symmetrical and rectilinear combinations. Is now made with increased illumination and rapidity and guaranteed fully equal or superior to the most expensive lenses of its kind. Next to the Antiplanetic Group Lens, Series II., it is the best lens for general work.

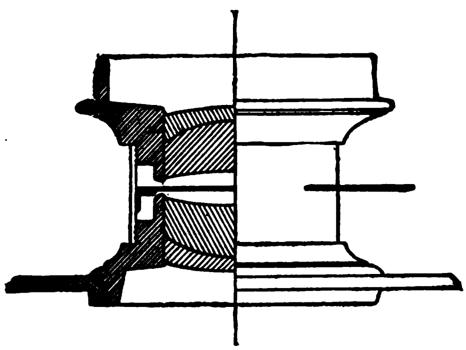
Nos. 5 to 10 inclusive of this Series are now furnished to order with an attachment allowing the distance between front and back combinations to be adjusted either for direct negatives or for copying from flat surfaces, thus practically giving the operator two lenses in one. For direct pictures approach the two combinations as near as the mounting will allow, and for copying separate them in the same manner, whereby the lens loses in depth and gains correspondingly in flatness of field.

Designed for *Portraits, Groups, Architecture, Landscape* and *Instantaneous Work.* Also *Copying*, if used with extension as above.

No.	Aperture. Inches.	Focal Length, Inches.	Size of Portrait or Group, Inches.	Size of View or Landscape, Inches.	Price.
1.......	¼	1⅝	For enlarging,		$ 18 00
2.......	⅝	3¾	3¼ x 3¼	4¼ x 3¼	18 00
3.......	1	5⅝	4¼ x 3¼	5½ x 4¼	25 00
4.......	1¼	7½	5½ x 4¼	7 x 5	32 00
4½.......	1 9-16	9½	7 x 5	8½ x 6½	38 00
5.......	1 11-16	11	8½ x 6½	10 x 8	44 00
6.......	2 1-16	14⅛	10 x 8	12 x10	57 00
7.......	2⅜	17⅜	12 x10	14 x11	86 00
8.......	2 15-16	21 3-16	17 x14	20 x17	125 00
9.......	3 7-16	25	20 x17	22 x18	166 00
10.......	4 9-16	33	22 x18	24 x20	245 00

Nos. 2 to 4 are made in matched pairs for STEREO WORK.

Series IV.—Rapid Wide Angle Aplanat.



Angle about 75 deg., and covering a larger field than the lenses of Series III. Effective aperture about f. 10. Specially designed for *Landscape Work* and *Architecture*, but can also be advantageously used for *Flash-light Interiors* and *Copying*.

Series IV.—Rapid Wide-Angle Aplanat.

No.	Aperture.	Focal Length. Inches.	Size of Picture. Full Aperture. Inches.	Size of Picture. Smallest Stop. Inches.	Price.
1.......	3/16	2⅜	2 x2	3¼x3¼	$18 00
2.......	⅜	3	3¼x3¼	4¼x3¼	21 00
3.......	½	4¾	5 x4	7 x5	26 00
4.......	¾	6⅜	7 x5	8½x6½	32 00
5.......	1	9½	8½x6½	12 x10	44 00
6.......	1½	15⅜	12 x10	17 x14	86 00
7.......	2⅛	23⅝	17 x14	24 x20	160 00

It is frequently desirable to get a picture from a given point and to get it just the size to cover your plate, or of any other given size without changing your position. This can only be accomplished by using objectives of different foci, by which you can reduce or enlarge the image at

will. For this work we have arranged a *Set of Four Single Aplanats*, fitting in the same flange, aperture 1 in., covering 8½x6½ with full aperture, and 12x10 with smallest stop.

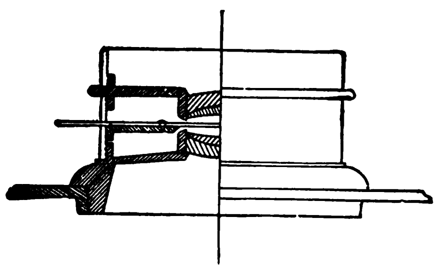
Used singly and by combination among themselves seven different foci are obtained as follows:

II in front with I behind,	7¾ in.	II single, - -	15⅝ in.
III " " " II "	10⅜ "	III " - - -	20¾ "
I single, - -	12⅝ "	IV " - - -	24¼ "
IV in front with III behind,	13 "		

Price in neat lock up case, $85.00.

Sets of any class and size of Aplanats made to order.

Series V.—Extreme Wide-Angle Aplanat.

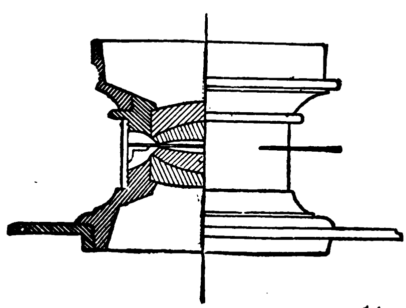


The proportionately short focus and large angle (about 100 deg.) of these lenses make them particularly adapted for *Interiors*, *Architecture*, and for very high, broad objects taken from short distances.

No.	Aperture. Inches.	Focal Length. Inches.	Size of Sharp Pictures. Inches.	Price.
1....................	3-16	3¾	5 x5	$26 00
2....................	5-16	4¾	7 x7	30 00
3....................	7-16	7¼	10¼x10¼	42 00
4....................	9-16	10⅜	12¼x12¼	61 00
5....................	14-16	16	18½x18½	93 00

Special quotations for larger sizes.

Series VI.—Wide-Angle Aplanat for Copying.



These lenses give perfect flatness of picture and sharpness of definition, and have at the same time a considerable field. Designed specially for *Copying Maps, Charts, Drawings, Paintings* and *Engravings* and *Photo-mechanical work generally.*

Series VI.—Wide-Angle Aplanat for Copying.

No.	Aperature. Inches.	Focal Length. Inches.	Size of Sharp Picture. Inches.	Price.
1................	1	14⅜	10 × 10	$75 00
2................	1¼	18	13 × 13	105 00
3................	1¾	23⅝	17 × 17	145 00
3b................	2	30¾	20 × 20	210 00
4................	2½	38⅜	24 × 24	320 00
5................	3	48¼	28 × 28	540 00
6................	3½	56	34 × 34	760 00

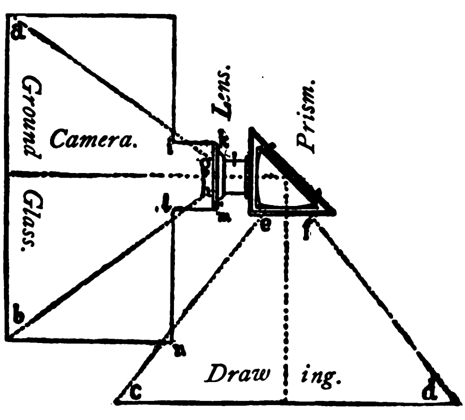
Special quotations for larger sizes.

It is only a few years since this lens has been brought to the notice of photo-mechanical establishments in the United States, but it was at once recognized as the very best lens for their work for which it has been specially designed. To-day this lens is found in every establishment where the production of the highest class of work is the first consideration.

As a result of our experience we beg to point out particularly the necessity of avoiding the slightest vibration during exposure, when it is desired to obtain the extremest sharpness of picture which these lenses are capable of producing. It is also advisable not to use too small a diaphragm as the diffraction caused thereby veils the picture.

For obtaining inverted negatives, without stripping the film, we have designed the Prisms of Series VII. which can be fitted to the above or any other lenses.

Series VII.—Prisms.



These prisms are made of one solid homogenous mass of glass, with silvered hypothenuse.

They are centered in their mountings and adjustable to our lenses simply by unscrewing the hood of the lens and screwing the prism in its place.

With every prism is furnished a rotary flange with set screw, allowing the prism to be turned and fixed at any angle to the horizon. Designed for making *Inverted Negatives without stripping the film*. Also for special and scientific work.

Series VII.—Prisms.

No.	To work with Lenses as follows:	Price.
1	Ser. III. No. 2, Ser. IV. No. 3, Ser. IV. No. 4.......... Ser. V. No. 1, Ser. V. No. 2..........................	$37 00
2	Ser. IV. No. 5, Ser. V. No. 3, Ser. VI. No. 1..........	41 00
3	Ser. III. No. 3, Ser. VI. No. 2..........................	45 00
4	Ser. II. No. 2, Ser. III. No. 4, Ser. V. No. 4..........	57 00
5	Ser. IV. No. 6, Ser. V. No. 5..........................	68 00
6	Ser. II. No. 3, Ser. VI. No. 3..........................	80 00
7	Ser. III. No. 5, Ser. VI. No. 3*b*, Ser. VI. No. 4..........	110 00
8	Ser. IV. No. 7..	125 00
9	Ser. II. No. 4, Ser. III. No. 6, Ser. VI. No. 5..........	155 00
10	Ser. VI. No. 6..	185 00
11	Ser. III. No. 7..	287 00
12	Ser. III. No. 8..	493 00

No charge made for *fitting* the above Prisms to Steinheil Lenses. For fitting to other makes of lenses the labor will be charged for at cost.

Series VIII.—Aplanatic Focusing Lenses.

These are a combination of three lenses, so constructed that, at a considerable focal distance and large field, they produce an even, undistorted picture, achromatic both inside and outside of the axis.

No.	Focal Length.	Linear Magnifying Power.	Price.
1.......	2⅜ in.	........about 3½ times.........	$12 00
2.......	1⅝ "	.... " 5 "	10 00
3.......	1 "	.... " 8 "	8 00

ROSS LENSES.

Ross's Lenses for Cabinet Portraits.

These Lenses have a flat field, and give remarkably brilliant pictures. They have Waterhouse Diaphragms and rack-and-pinion movement. No. 2 will cover 6½x8½ plate. No. 3 will cover 8x10 plate, and are very quick workers.

No. 2.—The Lenses, 3¼ inches clear aperture, 8 inches focus; should be placed at 18 feet from sitter...$140 00
No. 3.—The Lenses, 3½ inches clear aperture, 10 inches focus; should be placed at 20 feet from sitter... 156 00

Are in use in many galleries in the United States, to the exclusion of all others.

Ross's Rapid Symmetrical Lenses.

For Groups, Views, Interiors, Copying, and every kind of out-door photography. Giving an angle of from 50 to 80 degs. The "Rapid Symmetricals" being aplanatic, work with full aperture, and are, perhaps, the best and most useful Lenses an amateur or professional photographer can possess for general out-door purposes.

Size View.	Size Group.	Diam. Lenses.	Equiv. Foc.	Rigid Setting.
a 4¼ x 3¼	Stereo.	¼ inch	4½ inch	$32 00
a 5 x 4	4¼ x 3¼	1 "	6 "	34 00
7¼ x 4½	5 x 4	1 "	7½ "	42 00
8 x 5	7¼ x 4½	1¼ "	8½ "	46 00
8½ x 6½	8 x 5	1½ "	11 "	52 00
10 x 8	8½ x 6½	1¾ "	13 "	68 00
12 x10	10 x 8	2 "	16 "	84 00
13 x11	11 x 9	2¼ "	18 "	92 00
15 x12	13 x11	2½ "	20 "	116 00
18 x16	15 x12	3 "	24 "	148 00
22 x18	18 x16	3¼ "	30 "	200 00
25 x22	22 x18	4 "	34 "	240 00

(*a*) These Lenses are supplied accurately paired for stereoscopic purposes.

Waterhouse Diaphragms are supplied with these Lenses, as the apertures are too large to permit of Rotating Stops; but the latter can be adapted, if required, at small extra cost.

The Rapid Symmetrical Lenses are free from "flare" and distortion, and give absolutely straight marginal lines, rendering them invaluable for all kinds of architectural subjects, dimly-lighted interiors, copying, enlarging, etc. They are also used for instantaneous work with great success.

With smaller stops, each Lens covers the next size larger plate than that given, thereby greatly increasing the angle of view when desired. The two combinations being exactly similar, either can be used alone as an ordinary single Landscape Lens, the focus of which will be exactly double that of the compound.

They are the best universal **Lens made.**

Ross's Portable Symmetrical Lenses.

For Landscapes, Architecture, and Copying, give wide or ordinary angles, according to the stop used. Since the discovery of photography, perhaps, no lens for Landscape and Architectural purposes has had so great a share of popularity as the Symmetricals. This is doubtless attributable to their extraordinary definition and flatness of field, as well as the exceedingly portable form in which they are constructed. They are much used by amateurs, and are great favorites. For photo-lithographic work, they are unequalled.

No.	Large Stop.	Medium Stop.	Small Stop.	Equiv. Focus.	Price.
a 1	3 x 3	4 x 3	5 x 4	3 inch	$24 00
a 2	4 x 3	5 x 4	7¼ x 4½	4 "	26 00
a 3	5 x 4	7¼ x 4½	8 x 5	5 "	28 00
a 4	7¼ x 4½	8 x 5	8½ x 6½	6 "	32 00
5	8 x 5	8½ x 6½	9 x 7	7 "	40 00
6	8½ x 6½	9 x 7	10 x 8	8 "	48 00
7	9 x 7	10 x 8	12 x10	9 "	56 00
8	10 x 8	12 x10	13 x11	10 "	64 00
9	12 x10	13 x11	15 x12	12 "	72 00
10	13 x11	15 x12	18 x16	15 "	80 00
11	15 x12	18 x16	22 x18	18 "	96 00
12	18 x16	22 x20	25 x21	21 "	120 00

(*a*) These Lenses are supplied accurately paired for stereoscopic purposes.

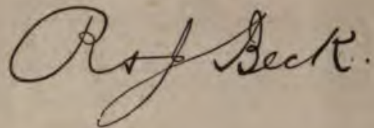
Nos. 1 to 8, Rotating Diaphragms. Nos. 9 to 12, Waterhouse Diaphragms.

The first ten of the series, having their screws alike, fit into the same flange.

These Lenses can be used with full aperture when only a limited field is required; while with smaller stops a wide-angle is obtained. They work with about the same rapidity as the ordinary-angle Doublets, their largest aperture being about equal to one-sixteenth of their focus. They give straight marginal lines, and, in consequence of the combination being placed so close together (leaving only just room enough for the diaphragm), they are absolutely free from distortion and flare.

Beck Autograph Rectilinear Lenses.

None genuine without this engraved on the tube.



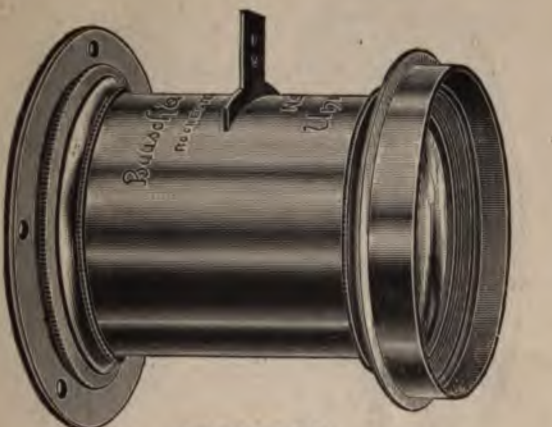
These Lenses possess qualities entirely their own.

5 x 4. Actual Size.

These Lenses are perfectly Aplanatic, covering with full aperture to the extreme corners the size plate for which they are designated in the list, and much larger sizes when moderately stopped down. They are very rapid in action rendering them particularly valuable for instantaneous and short-time exposures; are rigidly rectilinear and symmetrical; possess wonderful penetration and definition, and are the lightest and most compact of any lenses in the market—a matter of no small moment to the landscape photographer. The No. 5 Lens will make life-size heads, sharp and free from distortion. They are in use in many of the leading galleries of the country.

No.	Size of Plate.	Diameter of Lenses.	Back Focus.	Equiv'lent Focus.	Angle.	Price.
1	3¼x4¼	⅞ in.	4½ in.	5 in.	75°	$25 00
2	4¼x5½	1 in.	6 in.	6¾ in.	70°	30 0C
3	5 x8	1¼ in.	8 in.	8¾ in.	64°	35 00
4	6½x8½	1½ in.	10¼ in.	11 in.	67°	50 00
5	8 x10	1¾ in.	12¼ in.	13 in.	66°	60 00
6	10 x12	2 in.	14½ in.	16 in.	66°	75 00
7	11 x14	2¼ in.	16¾ in.	18 in.	66°	100 00
8	14 x17	3 in.	22 in.	24 in.	66°	160 00
9	20 x22	3¾ in.	27½ in.	30 in.	66°	200 00

Bausch & Lomb Rapid Universal Lenses.



(Full Size, 5x8, R. U.)

These Lenses since their first introduction have enjoyed an unusual popularity and are beyond doubt destined to become the best known Lenses in the American market, due to their merits only. We are desirous that they be compared in every direction with the best foreign productions of similar type. They are of the rectilinear, compound type, intended for studio work and all kinds of out-door photography. They are in no manner an imitation of any form, but have a construction peculiarly their own, the result of years of experiment to reach the highest results. The glass is specially manufactured for us of unusual hardness and brilliancy, involving specially favorable curves and the practical advantage that the Lenses are not liable to become scratched or undergo chemical changes. The cement is absolutely colorless and not liable to deterioration. The mountings are of neat design, well finished and carefully centered.

The diaphragm rings which we have introduced and have been in use several years, have found general commendation. They are readily attached or removed, and for ordinary work may be left undisturbed. By means of them the angle is reduced, giving unusual depth and flatness without affecting the speed to any extent. Without the rings, the Lenses have a speed given in the table below, with a covering capacity or flatness *at least* equal to that of any known Lens, and greater speed than any of the regular rectilinear Lenses. Every Lens is supplied with morocco cap and case and eight stops. Unless otherwise mentioned, we supply brass stops, but finding that hard rubber is excellently adapted to this purpose, and considerably lighter in weight, we also make them of this material and supply them in place of those in brass, when desired.

Nos.	Large Stop Covers.	Medium Stop Covers.	Diameter of Lenses.	Back Focus.	Equivalent Focus.	Largest Stop.	Price.	Telegraphic Code.
4¼	3¼ x 4¼	4 x 5	⅞ in.	4¾ in.	5¼ in.	ƒ6.7	$24 00	Ucubis.
5	4 x 5	5 x 8	1 1-16 in.	5¾ in.	6¼ in.	ƒ7.0	28 00	Umbria.
8	5 x 8	6½ x 8½	1⅜ in.	7¾ in.	8½ in.	ƒ7.0	34 00	Unca
8½	6½ x 8½	8 x 10	1⅝ in.	10⅜ in.	11¼ in.	ƒ7.5	42 00	Unelli.
10	8 x 10	10 x 12	1⅞ in.	12¼ in.	13 in.	ƒ7.5	58 00	Upis.
12	10 x 12	12 x 15	2⅛ in.	15 in.	16 in.	ƒ8.4	73 00	Uraca.
15	12 x 15	14 x 18	2⅝ in.	18 in.	19½ in.	ƒ8.8	88 00	Uxantis.
18	16 x 18	20 x 22	3⅛ in.	22¼ in.	23¾ in.	ƒ9.0	145 00	Utica.
22	20 x 22	21 x 25	4⅛ in.	28 in.	30 in.	ƒ9.0	195 00	Uzita.

ALVAN G. CLARK LENSES.

(Full Size, 6½ x 8½, A. G. C.)

Theses Lenses are of such quality and capacity that they mark an epoch in the construction of Photographic Objectives. They are the invention of Alvan G. Clark, the celebrated manufacturer of telescopes, and are of a construction dissimilar from anything heretofore followed, and are as striking in their results as Mr. Clark's success in the telescope objectives has been.

These Lenses may be used with equal facility in three directions.

1. To all work to which the Rapid Rectilinear type may be adapted, when they give an angle of about 60 degrees and in which capacity we enumerate them under List No. 1.

2. To all work requiring a medium angle objective, as enumerated under List No. 2.

3. Then they may be used as Wide Angle Objectives, having an aperture of nearly 100 degrees, and as which they may be used with larger stop than other specially constructed Wide Angle Lenses. They are quite free from marginal distortion and magnified perspective, so common to Lenses of this class. As Wide Angle Lenses they are quoted under List No. 3. *When using these Lenses in this capacity, care should be used in beveling the back of the front board so as to allow free passage of the rays.*

The Lenses are uncemented, each Lens of the combination being mounted for itself, and are therefore free from danger of gradual decrease in speed, so common in many Lenses owing to the chemical change in the cement. The crown glass is on the outside, and therefore less liable to become scratched. The mountings are unusually compact and each mounting has engraved upon it Mr. Clark's autograph as well as our firm name.

While these Lenses are intended to be used in all out-door work, they are also particularly suited to copying, enlarging and photo-engaving work, and are superb for portraiture, particularly for groups, covering the plates for which they are rated noticeably better than any others. Their characteristic qualities in almost every direction are of so high an order that we have no hesitation in claiming that they are superior to any Lens yet produced.

These Lenses are fully covered by patents. Mr. Clark has put their construction entirely in our hands, and the public has the double assurance of their absolute perfection and regularity in the combined efforts of Mr. Clark and ourselves to eliminate all faults by means of our improved manner of work and new critical tests.

These Lenses, although classified under different Lists, are marked as quoted in List No. 1.

Alvan G. Clark Lenses.

LIST No. 1.

Working with Stop F. 7.5.

No.	Size of Plate.	Diameter of Lenses.	Back Focus.	Equivalent Focus.	Price.	Telegraphic Code.
4¼	3½ x 4¼	¾ in.	4⅝ in.	5 in.	$25 00	Abel.
5	4 x 5	⅞ in.	5¾ in.	6⅛ in.	30 00	Abner.
8	5 x 8	1⅛ in.	7¾ in.	8¼ in.	40 00	Achan.
8½	6½ x 8½	1½ in.	10⅜ in.	11 in.	50 00	Adam.
10	8 x 10	1¾ in.	12¼ in.	13¼ in.	65 00	Agate.
12	10 x 12	2⅛ in.	15 in.	16⅛ in.	80 00	Alema.
15	12 x 15	2⅝ in.	18 in.	19¼ in.	110 00	Amasa.
18	16 x 18	3⅛ in.	22 in.	23⅜ in.	160 00	Arab.
22	20 x 22	4⅛ in.	28 in.	29½ in.	210 00	Arbah.

LIST No. 2.

Working with Stop F. 12.0.

No.	Size of Plate.	Diameter of Lenses.	Back Focus.	Equivalent Focus.	Price.	Telegraphic Code.
3	4 x 5	9/16 in.	3½ in.	3¾ in.	$20 00	Arbite.
4¼	5 x 8	¾ in.	4⅝ in.	5 in.	25 00	Abel.
5	6½ x 8½	⅞ in.	5¾ in.	6⅛ in.	30 00	Abner.
8	8 x 10 10 x 12	1⅛ in.	7¾ in.	8¼ in.	40 00	Achan.
8½	12 x 15 16 x 18	1½ in.	10⅜ in.	11 in.	50 00	Adam.
10	20 x 22	1¾ in	12¼ in.	13¼ in.	65 00	Agate.

LIST No. 3.

Working with Stop F. 35 0.

No.	Size of Plate.	Diameter of Lenses.	Back Focus.	Equivalent Focus.	Price.	Telegraphic Code.
3	5 x 8	9/16 in.	3½ in.	3¾ in.	$20 00	Arbite.
4¼	6½ x 8½	¾ in.	4⅝ in.	5 in.	25 00	Abel.
5	8 x 10	⅞ in.	5¾ in.	6⅛ in.	30 00	Abner.
8	10 x 12 12 x 15	1⅛ in.	7¾ in.	8¼ in.	40 00	Achan.
8½	16 x 18 20 x 22	1½ in.	10⅜ in.	11 in.	50 00	Adam.
10	21 x 25	1¾ in.	12¼ in.	13¼ in.	65 00	Agate.

"TRIPLEX" SHUTTER.

Two-Third Size 4 and 5 Shutter.

The Triplex Shutter, as will be seen by the cut, is in some respects similar to the "Duplex," the Shutter which has attained a world-wide reputation, and is to-day the best all-round shutter to be found. The Triplex has all its mechanism on the face of the Shutter (except the two exposing slides in the inside of the case, which are of steel and cannot get out of order), and all of its three movements, **TIME**, **SLOW INSTANTANEOUS** and **QUICK INSTANTANEOUS**, are operated by one pneumatic. Its method of opening and closing the aperture, by two oppositely pivoted slides swinging in opposite directions, half way and stopped for Time exposures, and a ***complete continuous*** movement for Instantaneous, has never been equalled. It is far superior to any iris arrangement in its method of admitting light, and is the only way great rapidity without jar can be obtained.

The Triplex will work from twice to four times faster than any shutter having an interrupted movement—as those which have slides or leaves which recede from centre or middle, to open, and return to close aperture. The Triplex, having but two exposing slides, there is much less liability to derangement than in Shutters which have more, and in all its other features it is equally superior in point of simplicity, durability and reliability, to any known Shutter.

The Shutter can be adapted to several kinds of lenses to which it is impossible to adapt any other, and we believe is the only Shutter which can be handily adapted into Detective Boxes, to be released by push trip or bulb at pleasure, and can also be reset and adjustment of spring made without opening box.

These Shutters are also made in a greater number of sizes than any other, which enables us not only to adapt Shutters to all sizes of lenses, but, what is of much importance, to furnish a shutter with the most desirable size of aperture corresponding with diaphragm of lens. Our Rotary Stops give facility of adjusting to proper stops while head is under cloth focusing; or when waiting for an approaching object, if sun becomes clouded or it suddenly brightens, making a change of stop desirable, it can be made instantly.

The method of making a **TIME EXPOSURE** is very simple. Air bulb is pressed and Shutter opens; when pressure is relieved it closes and is reset for another exposure. Any one who can count seconds can make Time exposures as accurately with this as with any Shutter with automatic attachment. It frequently happens that an exposure which is intended to be quite a lengthy one, owing to a breeze starting—if landscape work—or some one of a group moving, it is desirable to close shutter quickly. With

a set-time Shutter this cannot be done, but with the Triplex it is done as quick as thought. With **SLOW INSTANTANEOUS** movement the quickness of exposure anywhere from ¼ to 1/50 of a second ***can be made just as required, at the very instant of making it.*** Too much stress cannot be laid on the advantages of this feature. There are Shutters with which very slow exposures can be made, but the exposure ***must be what it is previously adjusted for;*** but with the Triplex, if in exposure on an animal, single person or group, the object remains quiet, the air bulb can be given a pressure so that as long as a quarter-second time can be given; but if it is restless and a shorter exposure is necessary to stop motion, by pressing bulb quickly the exposure can be made as short as 1/50 of a second.

As shown in cut, Shutter is held in open position by spring for focusing. To adjust for **TIME**, simply unhook spring. For **SLOW INSTANTANEOUS**, move hook 3 to upright position. For **QUICK INSTANTANEOUS**, hook on spring, throw in catch 1 and pull down knob 2, and shutter sets and locks.

The Triplex is adapted to any style of Detective Camera. When so adapted it can be released both by a push trip and by pneumatic bulb, for Quick Instantaneous; and for Slow Instantaneous and Time, by bulb only. Including Rotary Stops and necessary fitting to box, price $15.00. We require to have lens and box.

The **TRIPLEX STEREOSCOPIC** fills perfectly the want of a Time and Instantaneous Shutter for stereoscopic work. It consists of two Triplex Shutters on one frame, operated by one lever and one release, and consequently gives two identical exposures. Made in two sizes. No. 1, ¾ inch opening, price $18,00. No. 2, ⅞ inch, $19.50. Lenses are arranged at 3¼ inches from centres, but this will be increased up to 3¾ inches for $1.00 additional. Rotary Stops, $2. Flange Collars when required, 75 cents.

When no particular size Shutter is specified in order, lenses as a rule are adapted to Shutter having opening less than the largest diaphragm of lens. Thus a 6½ x 8½ lens is adapted to a No. 1 Shutter. Rotary Stops include ***five*** openings, largest corresponding with opening in Shutter, four others such as are thought best. Requests for special sizes are, however, complied with when possible. Rotary Stops up to size No. 1, price $1.50; over that size up to No. 2A, $2.00 extra, but not furnished above 2A.

Numbers	00	0	0A	1	1A	2	2A	3	3A	4	5
Openings, in	¾	⅞	1	1⅛	1¼	1⅜	1½	1¾	2	2¼	2½
Prices	$11.50	12.00	12.50	13.00	13.50	14.00	14.50	16.00	18.00	20.00	22.00

When flange collars are required, as on Ross and lenses similarly mounted, 50 cents extra.

Shutters can be furnished for most standard lenses, fitted ready for use, but it is to the customer's interest to forward his lens tube, otherwise perfect fit is not guaranteed.

We are also makers of the popular Duplex Shutter. This Shutter has one feature that many like, which the Triplex has not. Time exposures are made by two pulsations of air bulb; the first opening and the second closing the Shutter. With the added improvement of Silent Time and Slow Instantaneous movement (similar to the Time and Slow Instantaneous of Triplex), it has four methods of exposure, giving a greater range than any known Shutter.

While we guarantee these Shutters to be the quickest Shutters made—working both Time and Instantaneous—and *as quick as any purely Instantaneous* Shutters, we do not guarantee them quick enough to take, at *short range* horses running or trotting fast, and other extremely fast work. For this work we make a special Shutter, the "Prosch Rapid," and this we do guarantee. We believe this Shutter to be the only one quick enough for this kind of work. Made in two sizes. No. 1, with 1 inch opening. $18.00 No. 2, with 1½ inch opening, $22.00.

Scovill Time and Instantaneous Shutter.

That the substitution of a pneumatic release for the ordinary trigger on a wood drop-shutter greatly enhances its value, "goes without saying."

Scovill Safety Shutter, with Time and Instantaneous Attachment.

The Scovill Time and Instantaneous Shutter

Is Fitted with Pneumatic Attachment,

which may be worked at a considerable distance from the Camera, thus enabling the operator to form part of a group or to be included in a view he is photographing. This Shutter may be used for either timed or instantaneous exposures ; the change is made by simply moving a switch.

SCOVILL UNIVERSAL SAFETY SHUTTERS.

This Shutter is styled Universal, not only because more of the Scovill Safety Shutters are in use than of any other pattern, but because it can be arranged with a variety of openings, from ¼ to 2 inches at the center, as shown by the dotted lines of the accompanying illustration. Uniform distribution of light over the plate is insured bv the form of opening.

Scovill Universal Shutter.

The breakes on all these Shutters make them safe to use, by preventing a recoil with the resulting double exposure, and the jarring common to many Shutters, which in time breaks apart the glasses of a Lens where cemented together—hence the designation "Safety Shutters."

PRICE LIST.

No.	Width of Opening in Slide.	Scovill Universal Shutters.	Universal Shutters, with Pneumatic Release.	Scovill Safety Shutters.	Safety Shutters, with Pneumatic Release.	Universal Time and Instantaneous Shutter with Pneumatic Release.
1	1¼ ins.	$2.70	$4.20	$1.20	$2.70	$4.70
2	1½ "	2.80	4.30	1.30	2.80	4.80
3	1¾ "	2.90	4.40	1.40	2.90	4.90
4	2 "	3.00	4.50	1.50	3.00	5.00
5	2½ "	3.10	4.60	1.60	3.10	5.10
6	3 "	3.25	4.75	1.75	3.25	5.25

When ordering these Shutters, exact diameter of hood of Lens should be given, so that the proper circular opening may be cut out to exactly fit hood of Lens. If not stated, the Shutters will be sent without the round opening being cut.

Scovill Safety Shutter.

SCOVILL MAGIC FINDERS,

(PATENTED.)

Unequaled for Landscape Photography.

ORDINARY FINDERS are quite unsatisfactory, on account of the reversed image which they reflect. While, with the camera this reversal may be regarded as unavoidable, it is certainly a very undesirable feature in the finder, for it greatly interferes with the judgment of the operator as to the best arrangement of the desired picture.

The ideal finder is the one having two negative lenses of rectangular form, mounted close together in a nickel-plated frame, on the bottom of which is a sliding piece, by which the finder can easily be attached to the camera.

Looking through the finder from a convenient distance, say twelve inches, *toward the view to be taken, the operator sees before him a correct,* right side up, and delightfully brilliant and sharp miniature picture of the view before him, the little frame taking in the full picture projected by means of an instantaneous lens on the ground-glass of his camera. Two circles, marked in the exact centres of the front and back surfaces of the combination, serve to enable the operator to bring any certain part of the view to the exact centre of the picture by placing the eye so that the two circles cover each other, and at the same time adjusting the camera so that the selected part of the view appears inside the circles.

The Scovill Magic Finders are light, ornamental, easily adjusted and detached, and are now considered indispensable by successful view takers.

PRICE LIST.

No. 1, for	4 x 5	Camera,	$1 50
" 2, "	5 x 8	"	1 75
" 3, "	6½ x 8½	"	2 00
" 4, "	8 x 10	"	2 50

C. C. H. FOCUSING GLASS.

This is a desirable little instrument for aiding the operator in getting a sharp focus.

C. C. H. Glass.

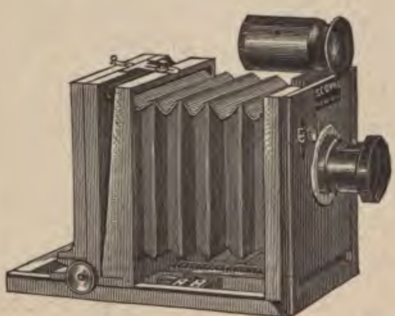
C. C. H. FOCUSING GLASS..................	$4 00
Darlot Focusing Glass	2 50
Scovill's Focusing Glass, each..................	75

Save your eyes by using one of these instruments.

WATERBURY FOCUSING GLASS.

Waterbury Focusing Glass, Rubber................ ....each, $0 50

PEERLESS VIEW FINDER, Each, $1.50.



THE

"WATERBURY FINDER,"

Each $3.00.

To Attach to Camera

FOR

Instantaneous Work.

THE

Scovill Sciopticon

No. 1 SCOVILL SCIOPTICON,
Complete with Double Slide Carrier,
$30.
No. 2 SCOVILL SCIOPTICON,
Complete with Double Slide Carrier,
$50.

After experimenting with most of the lanterns in the market, we have come to the conclusion that for parlor or small hall exhibitions, chemical and optical experiments, etc., the SCOVILL LANTERN affords, at a moderate price, the greatest number of advantages, and from its simplicity and non liability to get out of order, gives, even in inexperienced hands, results superior to all others.

The No. 1 SCOVILL SCIOPTICON when packed for carrying, in its own Russia iron case, measures 15 x 10 x 6 inches, and weighs 12 pounds: the case serving as a convenient stand when the lantern is in use.

The CASE and BODY of the Lantern are of Russia iron, and neat and compact in form. That part of the body which surrounds the lamp is double, the outer cover being ornamentally perforated so as to allow a constant current of air to circulate and keep down the temperature.

The lamp is of the triple wick variety, and so constructed that the three flames combine, and by the draught of a ten-inch chimney give a brilliant flame.

The CONDENSER is four inches in diameter, neatly mounted in brass, thoroughly ventilated, and arranged with screw flange so that the lenses may be separated and cleaned when required.

The CONE, which carries the objective, and the mount of that lens are nickel-plated. The objective is a double achromatic lens of one and a half inch clear aperture and five-inch focus, so that at a distance of twelve feet from the screen, it gives a brilliant picture on disc six feet in diameter. The focus is roughly obtained by sliding the front, carrying both cone and lens; and fine adjustment by a rack and pinion on the objective.

The No. 2 SCOVILL SCIOPTICON measures, when packed in case for carrying, 18½x12x8½, and weighs 19 pounds. The objective is a double achromatic lens of 1¾ inches clear aperture and 5½ inches focus so that at a distance of about 12 feet from the screen it shows a brilliant picture on disc eight feet in diameter. The lamp has five wicks and is correspondingly more powerful than the lamp with the No. 1 SCIOPTICON.

Fac-simile of Bronze medal awarded at the Boston Convention of the Photographers' Association of America, August, 1889, to THE SCOVILL & ADAMS CO., for improvements in Photographic Apparatus.

This was the only medal awarded by the Association for this contest in which there were twenty competitors

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